Spring 2014

Guidelines for Construction Companies to Decide Between Outsourcing and Self-Performing for Prefabricated Components

Sebastian Soto Ortiz
Purdue University

Graduate School ETD Form 9
(Revised 01/14)

PURDUE UNIVERSITY
GRADUATE SCHOOL
Thesis/Dissertation Acceptance

This is to certify that the thesis/dissertation prepared

By Sebastian Soto Ortiz

Entitled

Guidelines for Construction Companies to Decide Between Outsourcing and Self-Performing for Prefabricated Components

For the degree of Master of Science in Building Construction Management

Is approved by the final examining committee:

Bryan Hubbard

Bradley Benhart

Joseph Orczyk

To the best of my knowledge and as understood by the student in the *Thesis/Dissertation Agreement. Publication Delay, and Certification/Disclaimer (Graduate School Form 32)*, this thesis/dissertation adheres to the provisions of Purdue University's "Policy on Integrity in Research" and the use of copyrighted material.

Bryan Hubbard

Approved by Major Professor(s): _____

_____

Approved by: Bryan Hubbard 04/22/2014

Head of the Department Graduate Program Date

GUIDELINES FOR CONSTRUCTION COMPANIES TO DECIDE BETWEEN OUTSOURCING AND SELF-PERFORMING FOR PREFABRICATED COMPONENTS

A Thesis

Submitted to the Faculty

of

Purdue University

by

Sebastian Soto Ortiz

In Partial Fulfillment of the

Requirements for the Degree

of

Master of Science in Building Construction Management

May 2014

Purdue University

West Lafayette, Indiana

To my parents,

who inspire me to grow every day

to grow as a person and as a professional

and pushed me when I needed to correct my ways.

TABLE OF CONTENTS

Page

Page

LIST OF TABLES

Table Page

Table Page

LIST OF FIGURES

Figure Page

Figure Page

Appendix Figures

ABSTRACT

Soto Ortiz, Sebastian. M.S., Purdue University, May 2014. Guidelines for Construction Companies to Decide Between Outsourcing and Self-Performing for Prefabricated Components. Major Professor: Bryan Hubbard.

Prefabrication and modularization has been used in the construction industry for decades. It has recently made a resurgence worldwide providing increased productivity, safety, quality and construction schedule. This research has focused on the situation where a construction company has decided to use prefabrication and faces two possibilities, they either will self-perform or they will outsource the construction of the prefabricated components. The decision making process used by a construction company to determine whether to outsource or self-perform prefabricated components is examined and analyzed.

Prefabrication is an industrial process in which certain components are manufactured in a specialized facility. These items will then be assembled or installed on the construction site in their final position. Any component manufactured off-site and requires being assembled or installed to form a complete system can be considered as prefabricated.

Outsourcing is a strategy in which a company hires another to perform some of their work activities. In the construction industry, outsourcing is performed by highly specialized companies, typically subcontractors or suppliers. In prefabrication outsourcing refers to subcontracting another company to perform "manufacturing" of prefabricated components offsite with their own resources.

Self-performing refers to a company executing activities of a project by utilizing their own qualified labor, specific types of equipment, and have specialized knowledge on how to construct the components. In construction, self-performing is typically used for schedule sensitive, complex and critical activities. This allows the contractors to identify and solve construction issues, control the level of quality, and manage the safety processes. Contractors self-performing have advantage over those that do not because of these issues. When referring to self-performing or prefabrication, it means that a contractor would be in charge of setting up the off-site manufacturing facility and providing prefabricated components that will be assembled or installed in the project.

In order to provide guidelines for construction companies to decide between outsourcing prefabricated components (buying/outsourcing) or creating a new division dedicated to manufacturing the components (making/self-performing) a decision tool was developed. The most important reasons for outsourcing and the most important reasons for self-performing were identified in a survey. Using all the information as a base, a survey tool was developed, tested and forwarded to experts to fill. The results of the survey were processed

and analyzed in order to create a decision making tool to assist construction companies in their decision to whether outsource or self-perform prefabricated components. The tool is focused on construction companies who have had some experience with prefabrication in the past and are currently trying to decide if they should open a prefabrication facility to self-perform their own prefabricated components or if they should outsource them.

CHAPTER 1: INTRODUCTION

Statement of the Problem

Construction Industry

The construction industry is one of the largest industries in the US. In 2006 it contributed an added value 4.8% of the Gross Domestic Product (GDP) to the nation's economy; however, construction was also one of the sectors most affected by the recent economic downturn. As other industries contracted, fewer projects were developed and even fewer projects were built. In 2011, the construction industry hit bottom by contributing 3.50% to the American GDP (BEA, 2012) as shown in Figure 1.1.

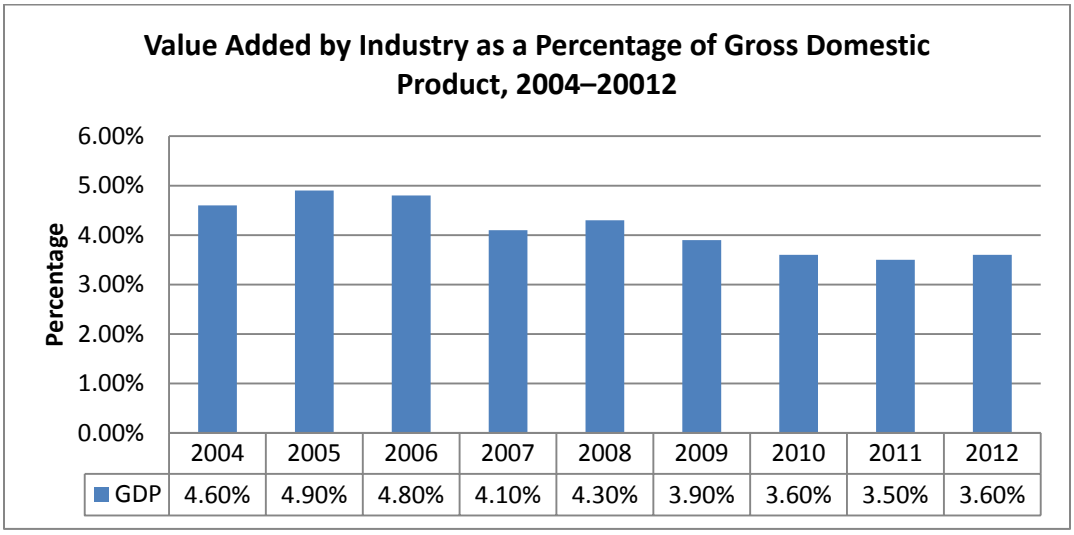


Figure 1.1: Value Added by Construction as a Percentage of Gross Domestic Product (Source: BEA Reports)

There are some important characteristics that define and make of the construction industry. Construction is extremely dynamic and competitive, much like manufacturing. Contractors and subcontractors must adjust to market demands if they want to remain profitable.

Comparing Manufacturing Industry to Construction Industry

To remain competitive, the manufacturing companies need to increase their productivity and/or decrease waste. They can do this by reducing the amount of rework, by streamlining their processes and eliminating activities that do not add value to the product (Benner & Tushman, 2013). Though, the construction industry has important differences that make it more complicated than manufacturing and make it difficult to apply manufacturing management theories directly. Manufacturing management principles must be adapted for application to construction (Perera, Davis, & Marosszeky, 2010).

Construction has special characteristics that distinguish it from the manufacturing industry. For example, construction is known for it is relatively low productivity and it is the only major industry in which “most of the improvements in productivity have been the result of Research and Development (R&D) work in the manufacturing industry that improve the productivity of construction machinery” (Forbes & Ahmed, 2011).

Other considerable differences are shown in table 1.1:

Table 1.1: Comparison between manufacturing and construction industries (part 1) (Soto, 2010)

Characteristics of typical manufacturing products	**Characteristics of typical construction services**
Sales are usually done after the product is completely manufactured.	Sales can start even before the construction begins.
Facilities are optimum for process improvement.	Temporary facilities are not optimum for process improvement.
The equipment can be optimized to each process because of the constant repetition.	The equipment varies depending on availability for rent, and price depends on the location of the work.
Plants and operation facilities can be located strategically.	Plants and operation facilities cannot be located strategically; they must be located based on proximity to the construction site.
Inputs are optimized due the many standardized processes.	A considerable amount of waste is produced due the many non-standardized processes.
The raw materials are mostly homogeneous or previously processed.	Many of the components used are handcrafted.
Optimal conditions for carrying out the processes.	Relatively high levels of unsafe conditions while performing the processes.
The company's overhead and senior management are usually located on the same facility.	The company's overhead and senior management are commonly located on the different places.
Most of the industrial products are mass-produced in large quantities which allow the company to lower costs (economy of scale).	Most activities are not repetitive which stops the company from getting the advantages of the economy of scale.
The product is frequently "mobile" and the operators are in a "fixed position". The product goes through various positions where the operators execute their activities.	The product is frequently in a "fixed position" and the operators are "mobile". The operators move around the product's fixed position.

Table 1.1 continued

Characteristics of typical manufacturing products	Characteristics of typical construction services
Production is stable and controlled within the environment.	Production is unstable and highly dependent on external factors.
Outsourcing and subcontracting levels are relatively low compared to the amount of activities.	Outsourcing and subcontracting levels are considerably high compared to the amount of activities.
Areas of the company are more open to change, innovation and new technologies.	Companies are more traditionalist which means it is very hard to implement changes and innovate.
Companies usually deal with skilled labor and low or no rotation of personnel.	Companies have to deal with poorly trained labor and high rotation.

All of the factors shown in table 1.0 are extremely relevant and affect the applicability of management theories to the construction industry. They explain why the construction industry productivity rates are not measured and directly compared to the productivity rates in manufacturing industry. Most projects are different from one another, and the design is different from one place to another and from client to client. Numerous construction companies have become experts in managing these challenges in different ways, others have found ways around these challenges and that has made them successful in an extremely competitive industry.

Looking at the factors independently, people who are knowledgeable about manufacturing processes but not connected to the construction industry may suggest common solutions. However, issues occur when these

manufacturing solutions are implemented because the factors affecting construction cannot be considered independently and must be considered holistically because these factors are connected in more than one way. For example, working in an open environment creates several risks to the people involved in the project. They are exposed to the extreme cold in winter or high heat during summer. The effect of the weather on productivity is an important variable which the contractors need to deal with to ensure safety. Someone may suggest improving work by constructing the project under a special cover, but because of the other factors such as the dimensions of a typical project, creating a microclimate for buildings is typically not viable.

Utilizing Manufacturing Theories in Construction

There are many examples of how the construction industry has successfully utilized theories from manufacturing. The trend has been that the manufacturing industry is the early developer of new concepts and the construction industry modifies these concepts and adapts them to improve productivity.

Many theories and applications from the typical manufacturing industry have been adopted and adapted in the last couple of years. For example, quality control history can be traced to the 13th century when craftsmen organized and formed unions called guilds (ASQ, 2013). In Great Britain, during the mid-1750s the world tended to follow this craftsmanship model and developed into the Industrial Revolution (1800's) when the emphasis on quality was on product inspections (ASQ, 2013).

All this concepts were not applied in construction industry until the early 1970's. When initially adopted, the concepts were inappropriate for the construction industry because of the inherent variability in every project and the difficulty to define "acceptable quality" when every client has a different requirement and perspective. An early example of quality control in construction was in 1975 when Takenaka Komuten Company embarked on a quality control program. Other construction firms started to look at other programs that could be used in the construction industry (Forbes & Ahmed, 2011).

Another example would be Lean Construction, which is based on Lean Manufacturing and was adapted to the construction environment. The origin of Lean theories comes from the Toyota Production System (TPS) which was developed between 1945 and 1948. Since then, it evolved into Lean Manufacturing and it was not until 1993 when Lauri Koskela and Glenn Ballard talked for the first time about "Lean Construction" in a conference in Helsinki (Forbes & Ahmed, 2011).

According to CII experts (2004) and Martin (2012), the construction industry will be short in skilled labor and it will be expensive in the near future. On the other side, manufacturing processes will keep becoming more efficient and cost effective.

One way that construction companies deal with skilled labor issues is by outsourcing (subcontracting) activities in which they do not have in-house capabilities. A subcontractor is a party that commits to undertake all or some of the contractual obligations of the contractor (main party) under a separate contract from the one between the contractor and the client. from the client's. According to the HM Revenue & Customs from UK and the Standard Industrial Classification (SIC), a subcontractor is a company that commits to undertake some or all of the construction activities instead of the main contractor and who, at the same time may also perform the operations itself or by having its own subcontractors (HMRC, 2013) (SIC, 2013) as shown if Figure .

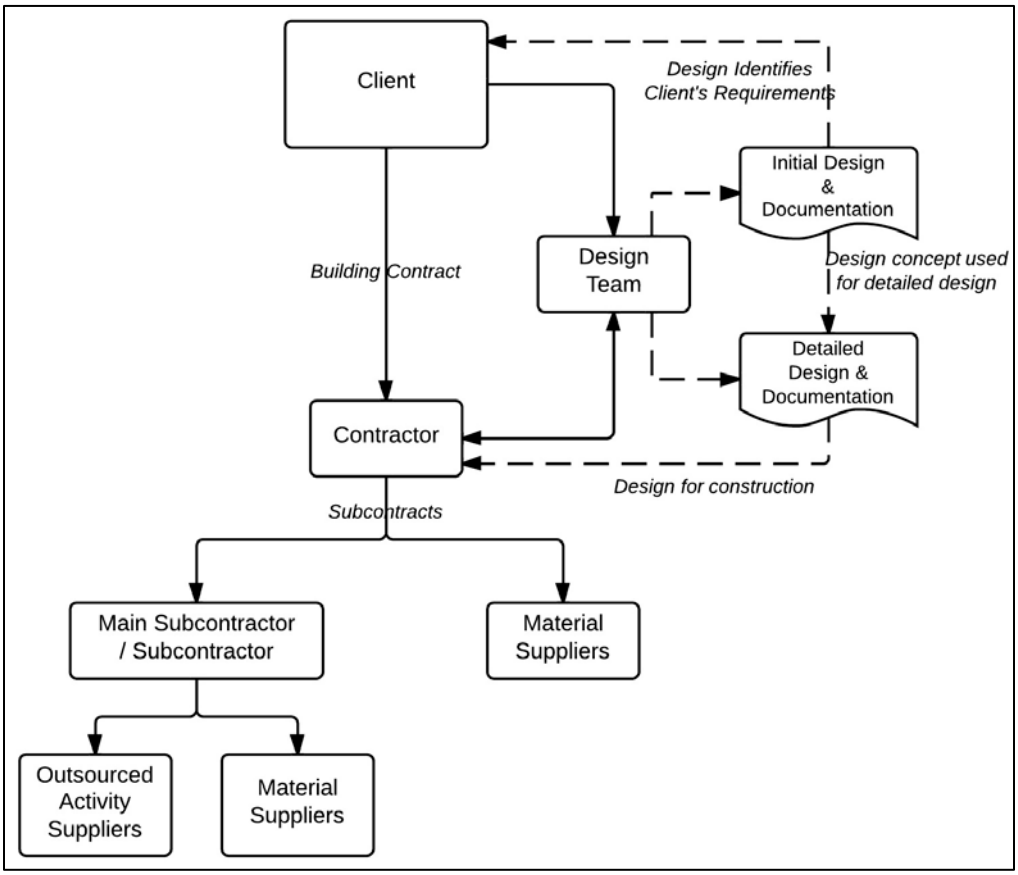


Figure 1.2: Relation Contractor – Subcontractor in a Design and Build Project adapted from (Ng & Skitmore, 2002)

Prefabrication

In the last couple of years, one of the activities that is typically outsourced (subcontracted) and has helped improve the productivity in construction is prefabrication. Prefabrication is a useful technique adopted from manufacturing that can help improve the productivity rates in construction. Prefabrication consists on fabricating and assembling components off-site which will be transported to the construction site for the final installation (Shahzad & Mbachu, 2012).

Prefabrication is not a new technology; there are examples that trace back to the Roman era. In Scotland, there is archeological evidence of the Romans using off-site fabrication of fortresses such as the Legionary Fortress at Inchtuthil (A. G. F. Gibb, 1999).

In the 1880's, there was also a proliferation of prefabrication when an epidemic of smallpox in Europe resulted in prefabricated temporary campus for the healthcare industry. In the U.S., pre-work originated in the housing industry. "Modern prefabrication in the United States can be said to have started over 100 years ago, when the wooden frame house was developed" (Hass, O'Connor, Tucker, Eickmann, & Fagerlund, 2000), a well-known example of these constructions in the U.S. are the Sears, Roebuck and Co. homes, between 1908 and 1940 there were around 100,000 prefabricated assembled homes (Sears, 2013). "These houses introduced into home construction the first elements of prescheduled procedures upon which modern mass production is based" (Hass et al., 2000). A similar increase in prefabrication came during the Second World War and post war when it was time to rebuild hospitals, houses and industries.

In 2009, it was considered as one of the "Activities with Potential for Breakthrough" in construction by the Board on Infrastructure and the Built Environment Division on Engineering and Physical Sciences National Research Council (CACPUCI, 2009). Prefabrication allows that many of the factors which made construction different than manufacturing be minimized. For example, some of the advantages associated with a successfully modularized and prefabricated project are:

- “Safety: There is less danger of fall-related injuries in manufacturing plants than on construction sites. Also, there may be fewer accidents at the plants because of the reduced use of heavy mobile equipment, scaffolding, and other potential hazards that are present at most construction sites” (CII, 1992).
- “Reduction of Construction Time: The duration of construction may substantially affect the final cost of the project. A shorter construction schedule may reduce the field mobilization duration and reduce the construction finance costs, improving owner cash flows” (CII, 1992).
- “Reduced Construction Labor Cost: Net labor costs are generally higher in construction than in manufacturing. Therefore, project components that are completed offsite at a manufacturing facility can result in potential savings in total project labor cost” (CII, 1992).
- “Labor Availability: Projects located in remote regions frequently experience problems stemming from the availability of skilled labor. Off-site prefabrication can be used to reduce the mobilization of skilled labor at the site and the resultant costs incurred from relocation and housing” (CII, 1992).
- Weather: Adverse weather conditions can decrease the construction productivity rates, such effects can be avoided with the off-site prefabrication (CII, 1992).

- Increased Quality and Efficiency: Many plants use a production line system where work stations are fixed, the tools and pieces are brought to the worker; quality control procedures can employed more effectively (CII, 1992).
- Simultaneous Production: In a conventional building, a general contractor has to finish the first floor to start working on the second. With prefabrication they can start working on several floors at the same time (CII, 1992).
- Fewer Interruptions to Operating Plant: Off-site construction can result in less construction down-time (CII, 1992).

However, as any technology, prefabrication has disadvantages:

- Transportation costs: Off-site prefabrication implies that the components are built at a manufacturing plant and these components have to be shipped to the project site for permanent installation; therefore, shipping costs for the project are increased (CII, 1992).
- Module Size Limitations: Each mode of transport, such as trucks, trains, or barges, have different restrictions regarding module size (CII, 1992).
- Increased Engineering Effort: Prefab requires a more intensive engineering effort. Engineering, design and compatibility of

specialties needs to be completed prior to module fabrication, which often requires more engineering to be accomplished within the same schedule. Earlier commitments for equipment purchases may be necessary to take advantage of the modular approach. This disadvantage is partially offset as planning and design decisions are forced earlier, helping to freeze the design and, therefore, reduce changes (CII, 1992).

- Offloading and Setting: Prefabricated parts have to be moved from transportation vehicles to a storage location or the final erection site. Cranes with a substantial carrying capacity or other lifting devices may be needed to set the heavy modules. Other special requirements for module handling, such as jacking, may be required. This effort may increase the cost of the project (CII, 1992).
- Interferences and Planning: Before starting the construction of a project, it is required to perform a complete interference analysis and lift planning in advance. Preplanning “these activities can lead to a higher performing project. However, it does mean that it is much more difficult to make modifications after a project has begun” (Hass et al., 2000). A current solution to this disadvantage is managed with BIM models that allow making different specialties compatible and preventing interferences.

- Setting up an off-site plant to produce prefabricated elements implies a higher initial cost that needs to be recovered in the project. Typically, the setting up of an off-site plant in not considered in conventional construction projects (Nadim & Goulding, 2010).
- Prefabrication cannot be used in every construction project: It involves changes, adapting designs and requires a certain level of standardization which is sometimes, is not viable for small projects.

There are also several believes myths that must be dispelled, like the prefab components cost should not be more than if the project did not use prefabricated components or that prefabrication requires a high degree of standardization to make of it a viable option (A. G. F. Gibb, 2001).

Construction companies who want to adopt prefabrication techniques in their projects will have to decide between outsourcing the activities to another specialized company or performing a backwards integration in the supply chain and opening a temporary off-site prefabrication facility.

Prefabrication is a helpful tool for construction companies if they have enough resources and know how to manage it. However, for companies that have no experience in prefabrication there are many barriers to overcome. These barriers include: a lack of awareness of the benefits, a lack of available expertise and knowledge within the industry of these methods, and a lack of methodologies for evaluating the possible use of prefabs and for making the decisions on the

type and scope of use (CII, 2004). This certainly represents a challenge that must be carefully planned and strategically managed considering that they would be moving into a “new type of construction”. According to Schleifer, bankruptcy is one of the most common reasons for contractor failure, and the vulnerability associated with a venture in prefabrication could result in bankruptcy and failure if the risks are not adequately managed (Schleifer, 1990).

Make vs. Buy

When a construction company has already decided to perform off-site prefabrication, they have to face a new set of questions: Should a firm perform their activities in-house, typically referred to as “make” or self-perform? Or should they obtain the construction components externally, typically referred to as “buy” from a subcontractor or supplier?

Make is the term typically used to refer to establishing direct, in-house channels (Peng, Zhou, & York, 2006). In the case of the construction industry, firms that self-perform the activities would fit in making or if they want to execute.

On the other hand, Buy refers to outsourcing services from intermediaries who perform certain tasks (Peng et al., 2006). In the construction industry, firms that use subcontractors and/or suppliers they would be buying.

In fact there are many parameters that may affect this decision: initial costs, available space and location, skilled labor, scope of work, and economy of scale. The evaluation of the potential parameters that a construction company has to consider when making the decision to outsource (buy) or self-performing (make) by opening a new subsidiary dedicated to prefabrication is a difficult task.

Other industries, such as manufacturing, have developed a better process for the make vs. buy dilemma. Manufacturing still hasn't mastered this decision making process, but as explained previously, manufacturing is usually ahead of construction when it comes to the development of theories and philosophies to improve their business. This is the reason why it may be useful to assess buy vs. make theories from manufacturing and adapt them to the construction industry.

The decision making between making and buying has become one of the key issues in the manufacturing industry. Senior managers and CEO's agree that the make vs. buy decision is so important that it should be a part of their business strategy because it can often determine the final profitability of the business; this means that it is a decision that may significantly contribute to the financial condition of the firm (Humphreys, McIvor, & Huang, 2002).

Conventionally, buying is made on the basis of getting the lowest price (low bidder), but other factors such as quality, timing, trust, technical capabilities and availability can affect the final decision. Additionally, some firms may find themselves with an initial position regarding make or buy that was inherited from the past and do not reevaluate their position considering their current position nor future goals (Humphreys et al., 2002).

All the decision factors from the manufacturing industries are common to the construction industry, and as such they are a baseline scenario which can be used to start adapting the latest theories in make vs. buy decision making from manufacturing to the construction industry.

Vertical Integration

Vertical integration involves a variety of choices concerning a company's decision to buy or make the inputs for their processes. Whether a company decides to buy or make, they participate in a "chain value" of activities, the chain represents a flow of processes to convert raw materials into completed products or services for a final consumer. Different processes are represented by the links in the chain and they are commonly performed by different companies (Rothaermel, 2013).

When a company decides to buy (outsourcing activities), they reduce their level of vertical integration within the chain value. On the other side, if they choose to make they would be increasing their level of vertical integration by performing processes of either the previous or the following links.

If the company opts to perform the activities of the previous links by owning the processes and inputs usually provided by suppliers and subcontractors, they would be performing a backwards integration; and, if they perform the activities of the succeeding links by owning the processes and outputs usually bought by the clients, they would perform a forward integration (Rothaermel, 2013).

Purpose of Study

A construction company who employs prefabrication in their projects will face the decision between outsourcing the tasks and self-performing the tasks. There are lessons to be learned from a historical review of historical prefabrication. Another source of knowledge that can improve prefabrication in the construction industry is the manufacturing industry and how they decide between making or buying. The motivation for this thesis comes from two needs in the market of prefabrication:

1. Study how decision making between outsourcing and vertical integration is made in manufacturing industry.
2. Propose guidelines for construction companies to decide between outsourcing and opening a new division dedicated to the manufacturing of prefabricated components for construction projects.

Research Question

The research question for this thesis is:

“What are the business parameters that a construction company should analyze in order to determine the best option between outsourcing prefabricated components (buying/outsourcing) or creating a new division dedicated to manufacturing the components (making/self-performing)?”

To answer this, the ideas identified in the Purpose of Study must be studied in conjunction with other concepts such as corporate strategies, off-site and on-site production, restrictions and barriers.

Methodology

The methodology for this thesis is:

1. Review of literature to identify prefabrication concepts.
2. Examine and explain the differences between outsourcing (subcontracting) and vertical integration (self-performing) in the manufacturing industry.
3. Develop a survey instrument and identify experts to interview.
4. Interview experts to identify the business parameters that should be analyzed to determine if they should outsource or backwards integrate to perform prefabrication activities.

In order to identify important parameters in prefabrication, experts will be surveyed regarding prefabrication and potential parameters that should be considered for construction companies that are trying to decide between outsourcing and backwards integration.

To provide additional information regarding prefabrication business parameters, in-depth individual interviews will also be used. The objective of the interviews is to get the additional information and the opinion of several experts and stakeholders regarding the initial survey results. It is expected that the interviews will either validate the survey results, clarify the implications of these results or suggest modifications or additional considerations (Creswell, 2009).

CHAPTER 2: LITERATURE REVIEW

The purpose of this research is to determine the critical parameters associated with the development of a business unit in a construction company that is dedicated to the manufacture of prefabricated components. This chapter presents the foundation upon which this thesis was built by focusing on two different points of view; prefabrication in construction and business analysis. This two must be joined and combined for a company to develop an adequate business plan and startup in manufacturing prefabricated structural components.

Construction

The Construction of a facility covers a considerable amount of activities with a wide spectrum of types of projects. Projects range from small, fast built and simple structures to relatively massive, time consuming, complex projects.

The term construction is usually referred “all types of activities associated with the erection and repair of immobile structures and facilities” (Nam & Tatum, 1988); more specifically, “construction is used to describe the activity of the creation of physical infrastructure, superstructure and related facilities” (Wells, 1985).

As mentioned in the previous chapter, many authors such as Forbes & Ahmed (2011) and Koskela (1998) state that construction has special

caracteristics that differentiate it from other productive activities. For example, construction produces a “one-of-a-kind” final product on a different site of production, and requires multi-organizations to construct. However, other authors state that other types of production also possess one or several of these characteristics:

- The uniqueness of projects: In Construction the projects are unique and may range from a single house to a skyscraper, every project is typically different. This characteristic can be found in some manufacturing industries when they start producing custom products for their clients.
- Site production: This characteristic differentiates construction from large manufacturing operations such as shipbuilding and airplane building. However, construction shares this site production characteristic with agriculture and activities such as mining, which are at the very beginnings of manufacturing’s value streams.

- Temporary multi company organizations: Temporary multi company organizations are commonly formed for every construction project. even among similar projects constructed by the same general contractor, the organizations will change or evolve. This trend in is also seen in manufacturing for custom products. Manufacturers will "projectize"[1] the manufacturing utilizing temporary multi-organizations (Koskela, 1998).

Koskela highlights the fact that construction is not a one of kind industry and proposes alternatives to reduce its uniqueness utilizing modularization and prefabrication, standardizing components and use of enduring teams.

Construction Industry

The US Census Bureau (2012) establishes that the construction sector is focused on the development and construction of buildings, heavy and industrial facilities.

Buildings and heavy construction facilities are typically built by general contractors. Specialty trade areas are typically outsourced to subcontractors and suppliers by a general contractor or project owner.

The economic census adds all construction parties that operated in the industry throughout a specific year or even for a part of it as long as it was industry related. Examples of establishments covered in this sector include:

[1] Apply Project Management theories in other fields.

- **Building construction establishments:** "are those that are responsible for an entire residential or nonresidential building project, including site preparation and development, new building construction, related additions or improvements, needed repairs, and installation of prefabricated materials and equipment" (US Census Bureau, 2012).
- **Heavy construction establishments:** "are those that are responsible for entire heavy engineering or industrial projects (except buildings), such as highways, tunnels, power plants, and pipelines. Also included are specialty trade contractors that do primarily heavy construction work" (US Census Bureau, 2012).
- **Specialty trade contractor establishments:** "are those that provide specialized construction services for building or heavy construction contractors. Examples of specialized construction services include excavation, well drilling, plumbing, electrical, painting, and demolition services" (US Census Bureau, 2012).

The construction industry is one of the largest industries in the world. In every region of the world, the construction industry has a considerable contribution to the GDP. As evidence, in Figure 2.1, the graph shows how the GDP has been developing in the last decade:

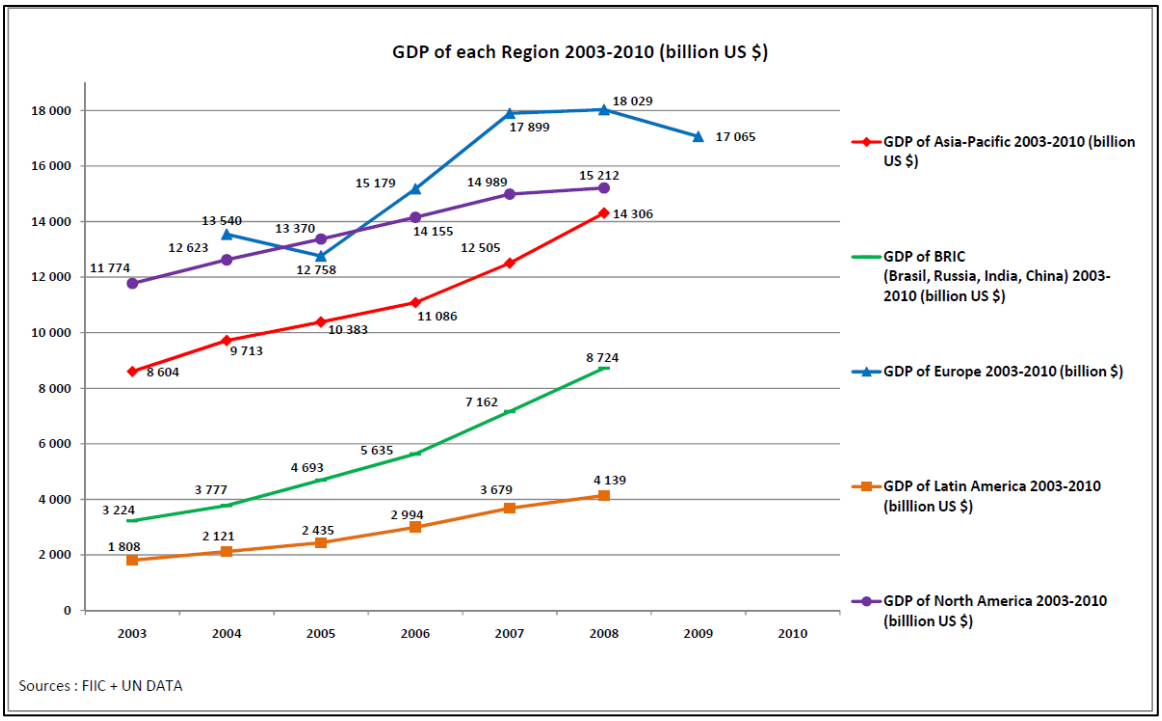


Figure 2.1: GDP of Each Region 2003-2010 (CICA, 2010)

Figure 2.2 shows the turn-over of the Construction Industry of each Region 2003-2010 in billion US dollars, which means that the level of business in construction is measured and compared among regions in billion US dollars.

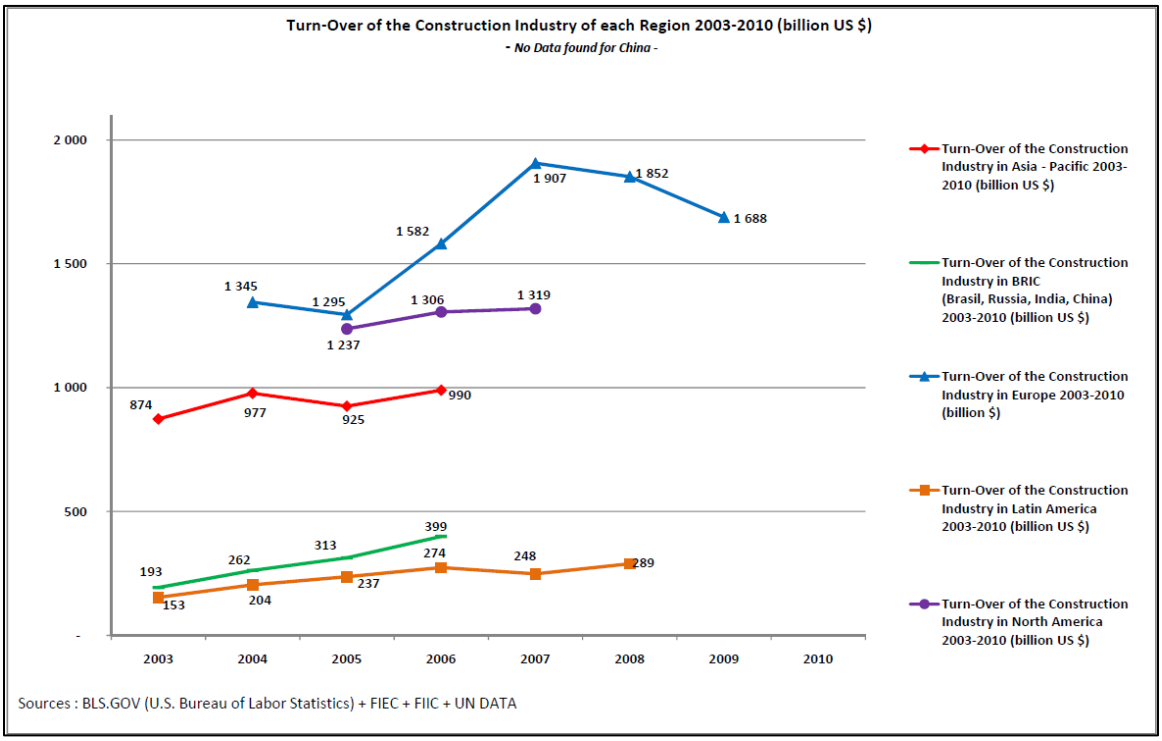


Figure 2.2: Turn-Over of the Construction Industry of each Region 2003-2010 in billion US$ (CICA, 2010b)

Finally, Figure 2.3 shows how much influence the construction industry has on the GDP in percentages.

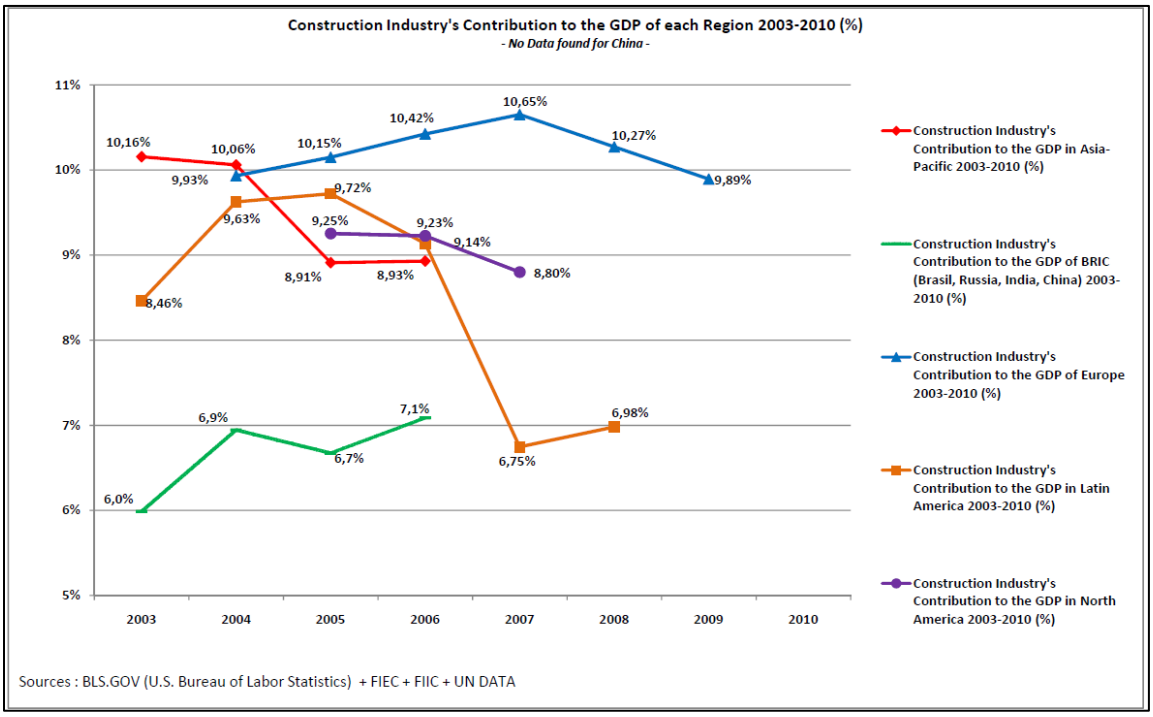


Figure 2.3: Construction Industry's Contribution to the GDP of each Region 2003-2010 in percentage (CICA, 2010b)

Based on the Construction Industry's contribution to the GDP one can conclude that the construction industry is extremely relevant, providing an average between 8% and 9% of the global GDP. The construction industry is a determinant factor of the domestic performance in a country's economy. It also serves as an essential growth enabler because of its wide and close relations with the other industries, for example, the manufacturing industry, which cannot grow if the facilities are not constructed before a certain firm starts producing of a determined product (e.g. basic metal products and electrical machinery) (Ankrah, Proverbs, & Debrah, 2009).

The construction sector is essential for the development of any nation. Because of this, construction is typically between the top three of major economic sectors in the developed and developing countries. Regardless of the different industrialization levels of different countries, the construction industry “usually generates one of the highest multiplier effects through its extensive backward and forward linkages with the other sectors of the economy” (Abdullah, 2004).

In the same way construction is essential for the development of any country, construction industry analysts agree that the sector is also tremendously dependent upon economic and political stability. This is because construction projects are necessarily long-term and heavily leveraged (Libaw, 1997). The economic and political stability of a country offers investors guarantees to spend their resources in infrastructure (private sector) and at the same time, the stability guarantees a certain flow and capacity of the governments to also invest in infrastructure (public sector).

The construction industry is essential for the growth of a country and a key sector in its economy. A country cannot grow if there is no development and infrastructure construction to spur the economy. The construction industry is an important factor in the process of country development by playing a major and vital role in transforming the aspirations and needs of people into reality. The contributions of the construction industry are more than just economic; the construction of roads, dams and irrigation works, schools, houses, hospitals, airports, railways, factories contribute extensively towards the creation of wealth and the quality of life of the population (Ibrahim, Roy, Ahmed, & Imtiaz, 2010).

Construction and changes

At the time a country develops, the scale of the construction projects grow as well; with this growth a larger number of professionals is required, the life project cycles increase, and the complexity rises. This is the reason why the complexity of construction operations have increased and construction professionals require now more specialized knowledge.

Authors such as Hawk (1992), Bakens (1992) and Louwe and Van Eck (1992) affirmed that even though every construction project is different and the processes are unique, the traditional organization of the construction procedures are the essential (Bakens, 1992; Hawk, 1992; Louwe & van Eck, 1992). Experts have recognized that the organization of the building procedures have become a major problem and may a limit innovation in construction (Pries & Janszen, 1995).

With the latest social, economic and political events around the world, traditional construction ways for executing and managing construction projects face unique challenges. The complexity and requirements for a particular industry such as construction forces organizations to rethink their management systems, production systems and quality systems (Kärnä & Junnonen, 2005). The construction industry may benefit from best practices in other industries that have been through a similar process to face these new challenges (Duggirala, Rajendran, & Anantharaman, 2008).

As a substantial part of any nation's economy, it is vital that constructions challenges its traditional way of working. The construction industry needs to become more innovative and able to provide greater value for money through instilling learning in their organizations (Murray & Langford, 2003). This is particularly challenging for an industry that has a culture that resists the change associated with the adoption and diffusion of innovation and knowledge (Barthorpe, Duncan, & Miller, 2000), but are also reluctant to connect the intellectual capital that drives innovation (Egbu, Botterill, & Bates, 2001).

The industry needs to prepare for those changes and break the traditional paradigms to improve its competitiveness to the levels the market requires and that can be achieved by using good practices, advanced construction techniques and optimize resources utilization. In other words, the construction companies need to work on differentiation strategies that will provide them competitive advantage and allow them to deal effectively with the market's requirements (Porter, 2008).

Because construction is such an attractive industry to investors, “many new construction companies enter the industry every year because starting a new company does not require a large investment; consequently the construction industry becomes more competitive and forces existing companies to seek advantages over competitors by means of differentiation strategies” (Isik, Arditi, Dilmen, & Birgonul, 2010) to get awarded with new projects that the new entrants cannot execute.

Prefabrication and Modularization

Prefabrication and modularization have been in the construction industry for many years. However, current market conditions and other trends such as the lean construction, increasing use of BIM technologies and rising impact of green buildings have made of prefabrication and modularization a perfect technology to be implemented in construction projects (Bernstein, 2011).

Prefabrication and modularization are strategies that can be used for mass production of construction components that have successfully worked in the manufacturing industry, (Erixon 1998, Hvam et al 2008, Ulrich and Eppinger 2008). Nevertheless, construction companies must not forget how important it is to generate value for the client as well, so prefabricated or modularized components need to be configured according to client’s requirements (Jensen, Hamon, & Olofsson, 2009).

The “philosophy behind “manufactured construction” is that the amount of effort needed to achieve the same result would be significantly less if some activities are moved to a manufacturing facility rather than being performed on a construction site where the workers will be exposed to the elements” (Arif & Egbu, 2010).

Prefabrication and modularization offer many benefits for the construction industry such as more control on the processes, which also allows improving safety conditions and quality of the components. The reduction of construction time on the construction site is also an important benefit for both, the clients and the contractors. The controlled conditions in a manufacturing plant can increase productivity rates and also reduce labor costs. Prefabrication and modularization also allows the general contractor to manage risks related to the weather by reducing or even eliminating some of the uncertainty about meeting the schedule (CII, 1992).

Gibb and Isack (2003) classified manufactured construction into four categories as shown in Figures 2.4 and 2.5.

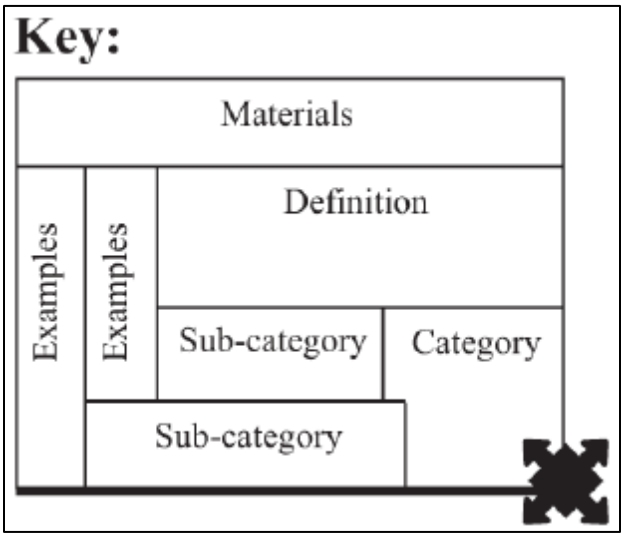


Figure 2.4: Key for reading Figure 2.5 (A. Gibb & Isack, 2003)

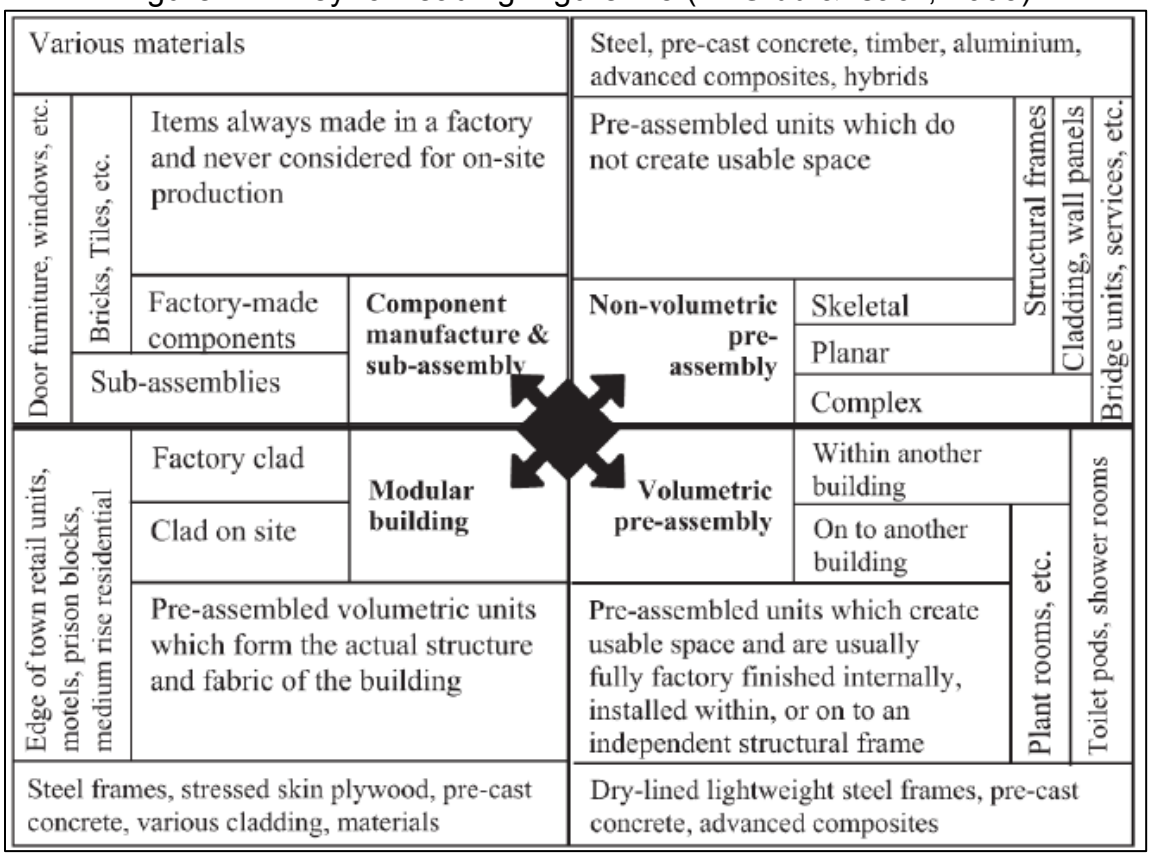


Figure 2.5: Four categories of pre-assembly, definitions, subcategories, examples and main materials (A. Gibb & Isack, 2003)

- “The first of the four categories is the component manufacture and sub-assembly. This includes items that have always been made in a factory and would never be considered for on-site production. Items in this category include bricks, tiles etc.” (A. Gibb & Isack, 2003).
- “The second category is non-volumetric pre-assembly. This type deals with manufacturing components in a factory that do not create a usable space like pre-fabricated wall panels. The non-volumetric units are then brought on the construction site and installed onto a structure of either steel frame or concrete frame” (A. Gibb & Isack, 2003).
- “The third category is the volumetric pre-assembly. In this type the pre-assembled unit which create usable space are usually factory finished and installed on the construction site onto an independent structural frame. This type of technique is used to manufacture plant rooms, toilet pods, shower rooms etc.” (A. Gibb & Isack, 2003).

- Finally, “the last category is modular building. In this type of construction pre-assembled volumetric units which form the actual structure and fabric of the building are manufactured in a factory and then transported on-site to be assembled. In this type of construction the majority of effort is concentrated in the manufacturing floor and only the final assembly and the finishing activities are performed on construction site” (A. Gibb & Isack, 2003).

There is a fifth category in this classification, which could be considered as a “hybrid” system. It is a mixture of two or more categories. The most common hybrid systems used in commercial and residential buildings are a combination between the volumetric and non-volumetric systems (A. Gibb & Isack, 2003).

Regardless of the type of prefabricated component, the contractor will have to decide who will be the one responsible to execute the manufacturing of these components. The component will either be outsourced by hiring a specialized subcontractor or self-performed by the contractor. The decision on either outsourcing or self-performing the work must be carefully analyzed from a strategic management point of view. The decision must also align with the business strategy of the contractor.

Strategic Management

Strategic management has many definitions based on business literature. These differences arise from different perspectives of economists, CEO's and managers.

The English word strategy has its roots in ancient Greek, the word "*strathgi"*, which meant "the art of generalship" focusing on planning and executing a military campaigns. As such, the word strategy was adopted from its military use into a business connotation because the qualities of a professional with military training were considered a good manager. Businessmen considered strategy as an advanced role of business leaders (Hindle, 2009a).

However, now some business experts see strategy as "The goal directed actions a firm intends to take in its quest to gain and sustain competitive advantage" (Rothaermel, 2013). This means that strategic management involves the planning and actions for a company to obtain a superior performance than its competitors, making of it a leader in the market.

According to Rothaermel, strategic management is about:

- Sustaining a competitive advantage.
- Maintaining differences with competing rivals.
- Creating value while containing costs.
- Deciding what to do and what not to do.
- Combining a set of activities to stake out a unique position.

- Requiring long term commitments that are often not easily reversed.

Strategy is broken into three distinct levels to determine; 1) where to compete, 2) how to compete and 3) how to implement the strategy. Strategic management usually differentiates among functional, business and corporate strategy. Functional strategy focuses on actions to be taken in one specific functional area or division that aid in the implementation of a business strategy. “The business strategy deals with the ways in which a single business firm or an individual business unit of a larger firm competes within a particular industry or market. The corporate strategy will deal with the ways in which a corporation manages a set of businesses together” (Grant, 2008). Figure 2.6 represents the differences between each type of strategy.

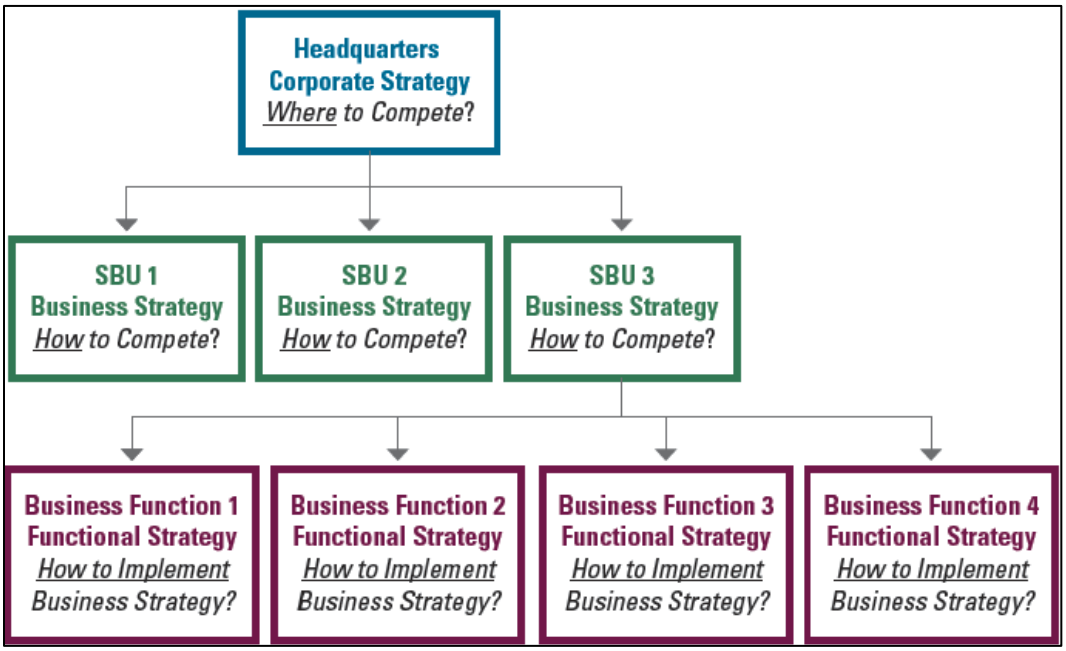


Figure 2.6: Strategy formulation across levels, adapted from Rothaermel, 2013[2].

Corporate Strategy

As noted, a corporate strategy focuses on gaining a competitive advantage and involves high level management decisions on where to compete (markets, industries, geography, etc.). The corporate executives determine the scope of business and their objective is to increase overall the corporate value.

[2] SBU refers to Strategic Business Unit.

Corporate strategy is broken into three dimensions:

- Industry value chain: Industry value chain refers to the transformation of raw material into finished goods and services along vertical stages. The level of participation of a firm in this value chain is referred as Vertical Integration.
- Range of products and services: The range of products and services refers to diversification, which is often referred to as Horizontal Integration
- Where to compete: Where to compete refers to geographical positioning (Rothaermel, 2013).

Industry value chain

The value chain is a metaphor to explain the amount of processes, inputs and outputs between extracting raw materials and obtaining a final finished product or service for the final consumer. Hindle (2009c) explains: “Each link in a value chain consists of a bundle of activities (value activities), and these bundles are performed by a firm to “design, produce, market, deliver and support its product” Hindle (2009c). Rival firms may have similar chains, but they may also have very different ones”. Those differences are a principal source of competitive advantage for any business.

Within the vertical chain, there are many possibilities for a company to get into an industry. The choice of a firm between making or buying a component is based on their resources and capabilities.

Platts, Probert, & Cañez proposed a framework showing that the decision processes for make vs. buy are affected by the external environment (Figure 2.7), which triggers the make-or-buy analysis. For example, the increased price of competition in the market place forces a company to look at ways of reducing costs. The increased competition may raise the make-or-buy question. The framework then suggests four areas within which to group factors that need to be considered when make-or-buy decisions are made: technology and manufacturing processes, cost, supply chain management and logistics, and support systems (Platts, Probert, & Cañez, 2002).

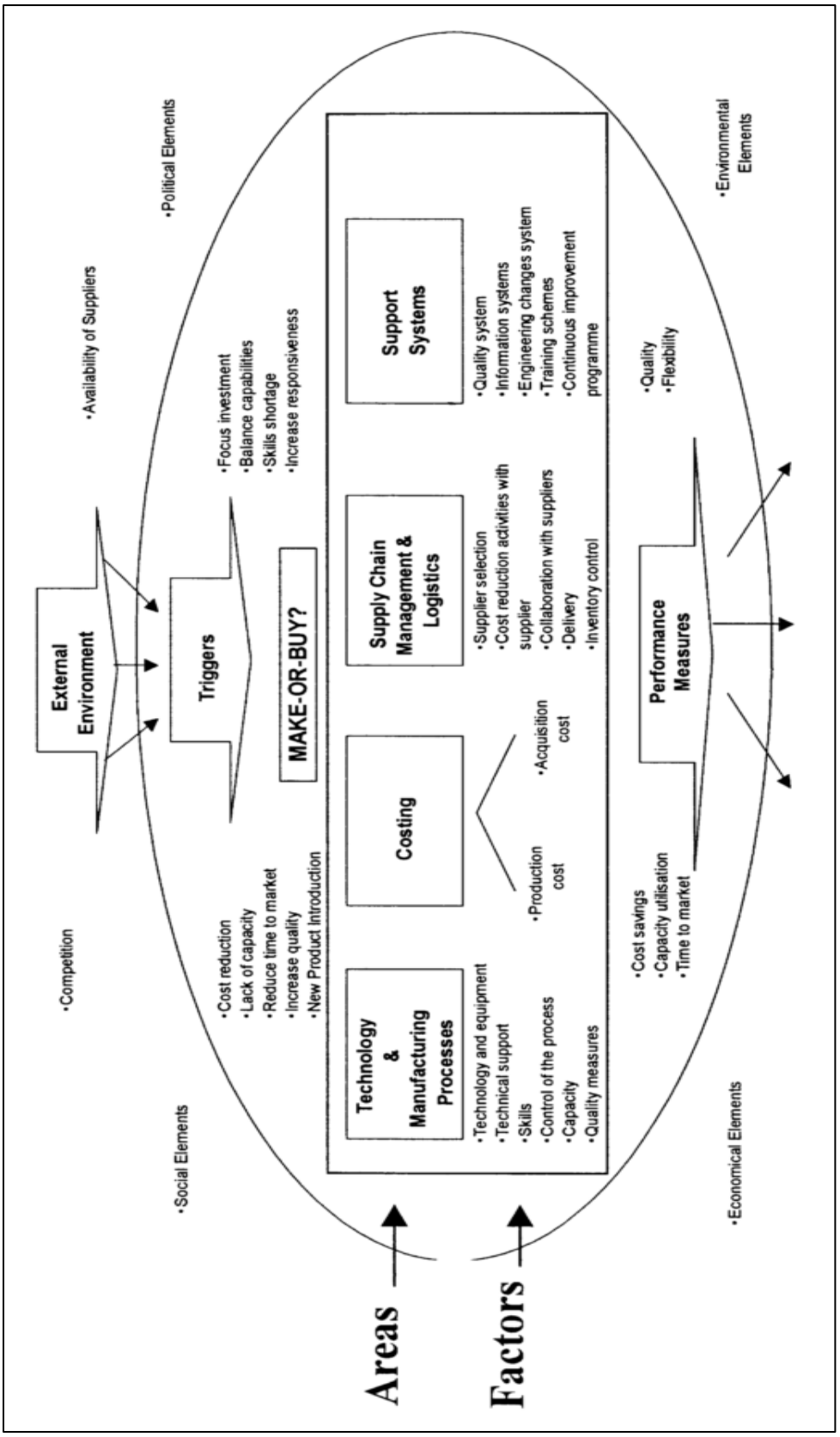


Figure 2.7: Framework for make vs. buy decisions (Platts et al., 2002)

The traditional approaches to questions of make vs. buy have been based on financial and economic criteria. There are also significant strategic issues behind most make vs. buy decisions. For example, it is essential to study the current conditions and the future potential technological capabilities within company. Is the company capable, either now or in the future, of making the component in-house? One cannot gauge a firm's outsourcing possibilities without looking at how a particular decision will affect the strategies of its competitors. Much work has been done by workers in supply chain management in identifying issues around the make vs. buy decision (Platts et al., 2002).

In between the options of make or buy, there are several hybrid alternatives arrangements that involve some benefits and disadvantages of these two extremes. Possible alternatives include:

- Short term contracts
- Strategic alliances
- Equity alliances
- Joint ventures
- Parent – subsidiary relationships (Rothaermel, 2013)

Figure 2.8 shows the alternatives to make vs. buy. Make and buy are at the extreme ends. The alternatives in the middle are the available hybrids. Firms will choose an option according to their needs, considering that the closer the alternative is to one extreme it will be more or less integrated in the vertical chain. The buy decision is less integrated, while the make is more integrated. Within the construction industry, the most common strategic alliance are short term contracts. For this thesis we will focus on the short-term contracts because the construction companies employ this is alternative in every project by subcontracting different activities.

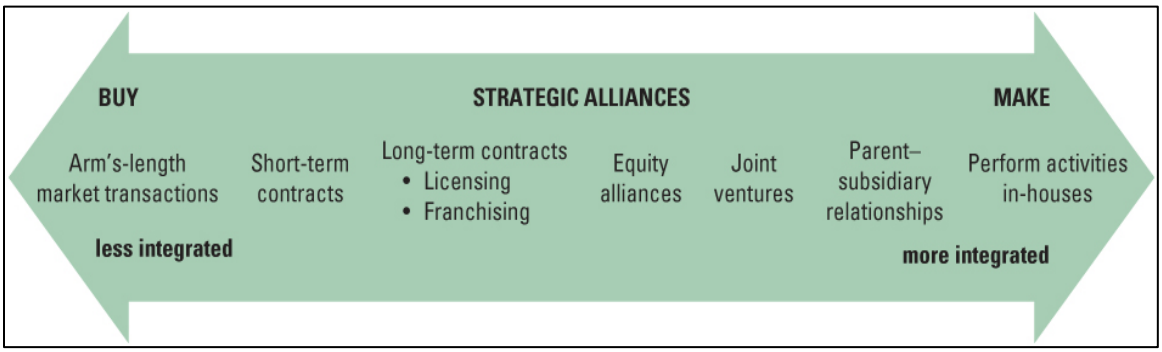


Figure 2.8: Make vs. Buy alternatives (Rothaermel, 2013)

Within the construction industry, the most common one are the short term contracts.

Short term contracts (subcontracting)

Short term contracts are a way to outsource certain activities by engaging short-term contracting. The process usually starts with a request for proposal (RFP) to several companies; usually subcontractors or suppliers in the construction industry (refer to Figure 1.2 to see the relation Contractor – Subcontractor in a typical project). This process initiates a bidding contest for a short term contract (generally less than one year).

The benefit of this approach in manufacturing industries is that it can lower prices due to the competitive bidding process; however, short term contracts are unlikely to be of strategic significance for the subcontractors or suppliers.

Outsourcing with short term-contracts is a current trend. As discussed previously, for a long time it has been considered as a method to decrease costs, however, these reductions can be merely attained under specific circumstances (Lacity & Hirschheim, 1995).

Outsourcing tasks, products or services is also a tool for top managers to spread risks in a more optimal manner. By using subcontractors and suppliers, they can avoid large, often irreversible, investments (Alexander and Young, 1996b).

Some of the benefits of this method in the construction industry are that it allows subcontractors and suppliers to help the contractors obtain the market's leadership by contributing with high-skilled labor, high-quality products and expert services and by doing that they mitigate the contractor's risks. These relations are so important that some larger contractors have established and preserved long-term relations with their key subcontractors and suppliers (Chiang, 2009).

González-Díaz, Arruñada, & Fernández made a table showing factors and their incidence on the subcontracting decision for construction firms:

Table 2.1: Incidence in subcontracting decision. Adapted from González-Díaz, Arruñada, & Fernández, 2000

Factors	**Incidence in the subcontracting decision**
Hold-up problems (specificity)	Negative
Uncertainty	Null
Interaction between specificity and uncertainty	Negative
Output dissimilarity	Positive
Geographical dispersion	Positive
Intangible assets	Positive or Negative depending on conditions
Shortage of capacity	Positive

Vertical Integration

Whether a company decides do buy or make within an industry, they become a part of the chain value. The chain value depicts each stage in any industry, from raw materials to components, final assembly, sales and after-sales. In other words, when a company decides to go into a certain industry, they become a part of the chain with many processes, and each process has inputs and outputs until the product or service reaches the final consumer (Rothaermel, 2013).

The concept of vertical integration comes when a firm focuses on different stages of production and provides itself by its own inputs and outputs.

Businesses are considered to be downstream or upstream of each other depending on their relative position to the final consumer's. The closer a business is to the final consumer is considered to be downstream, while the further away a business is it is considered upstream as shown in Figure 2.8. So if a company decides to integrate the previous activities to produce some of the inputs required in their core activity (upstream) they would be performing a backwards integration. On the other hand, if the company decides to integrate to the downstream activities they would perform a forward integration.

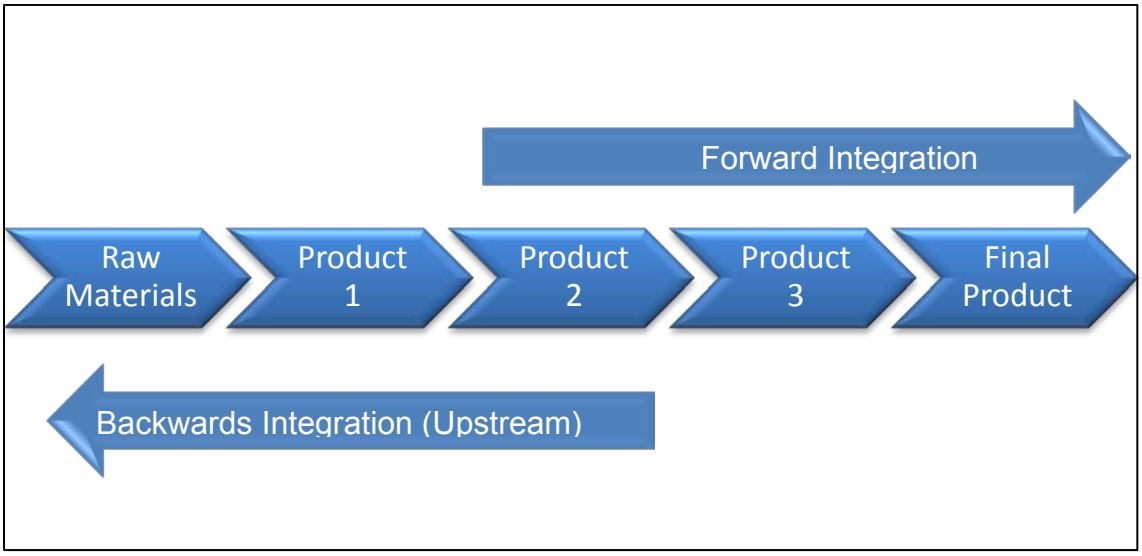


Figure 2.9: Representation of the vertical chain and vertical integration alternatives

Vertical integration offers the business some important benefits that derive from the increased capacity to control the flow of their own inputs (and to control the cost, quality and delivery times of those inputs).

"Vertical integration is a difficult strategy for companies to implement successfully. It is often expensive and hard to reverse. Upstream producers frequently integrate with downstream distributors to secure a market for their output. This is fine when times are good. But many firms have found themselves cutting prices sharply to their downstream distributors when demand has fallen just so they can maintain targeted levels of plant utilization" (Hindle, 2009b).

From the economics point of view, when the costs of pursuing an activity in-house are less than the costs of transacting for that activity in the market, then the firm should vertically integrate by owning production of the needed inputs or the channels for the distribution of outputs. (Rothaermel, 2013).

As any other strategy, vertical integration (backward or forward) has its own risks and benefits to be considered before taking any action.

Benefits:

- Securing critical supplies: By controlling upstream or downstream activities in the vertical chain, firms can effectively plan and respond to changes in demand flows (Rothaermel, 2013).
- Lowering costs: Vertical integration allows the firms to increase operational efficiencies through improved coordination and fine-tuning of adjacent value chain activities. Vertical integration also reduces the final product price by reducing the amount of participating companies that obtain profit during the production flow from raw material to the final consumer. In other words, this prevents double marginalization. As a consequence of this, firms may lower their costs (Lin, Parlakturk, & Swaminathan, 2013).
- Improving quality: the lowering costs tend to encourage more investments in quality improvement (Lin et al., 2013).
- Facilitating scheduling and planning: When a firm knows the demand of their goods they can control their production to fit the need of the market. Vertical integration allows firms to better predict the market's demand (Rothaermel, 2013).

Risks:

- Increasing costs: Higher cost structures within the firm. Knowing that there will always be a buyer for the upstream activities may produce a possible loss of incentives to compete (internal suppliers).
- Reducing quality: Single captured customer can slow experience effects.
- Reducing flexibility: Slow to respond to changes in external factors such as technology or demand.
- Increasing the potential for legal repercussions: Government regulators such as the Federal Trade Commission (FTC) and the Justice Department (DOJ) tend to allow vertical integration arguing that it generally makes firms more efficient and lowers costs, which can benefit the final consumers. However, vertical integration might also result in monopolistic conditions which may be investigated by the regulators.

One of the most important characteristics of the construction industry is the uniqueness of its projects and components as well as the diversity of areas, intermediate firms and quantity of outputs and inputs that occur at the same time and place. This means that the integration of some or all the activities require additional effort by controlling and coordinating among all the involved participants. By outsourcing activities, the contractors decrease their need to control and manage the amount of detailed information, so they can lower their monitoring costs (González-Díaz et al., 2000).

That is why when a contractor outsources an activity, they require less staff involved in the project and the fewer members they have they only need to monitor the quality and timing of the outputs. On the other hand, if the contractor decides to vertically integrate such an activity it has to know the details of the production process, assign the proper resources on time (González-Díaz et al., 2000).

CHAPTER 3: METHODOLOGY

After an extensive review of literature on the construction industry, prefabrication, outsourcing and vertical integration; a research methodology was developed to address the unique nature of this exploratory research. As depicted in Figure 3.1, an explanatory sequential design was selected to deal with data collection in two phases. Phase 1 starts with the collection and analysis of quantitative data. The second phase is the collection and analysis of qualitative data through an interview process.

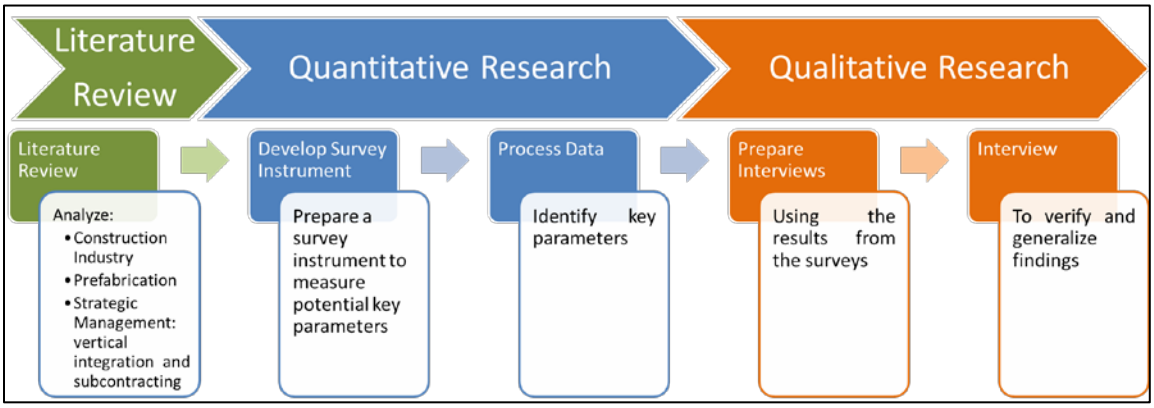


Figure 3.1: Mixed research design

This method was selected because of its focus on the qualitative portion of the research. It begins with a broad concept and seeks to gain a deeper understanding of the problem by looking at common themes in the analysis.

As represented in the Figure 3.1, this type of studies usually take longer than others because data collection process is very linear and need to be executed in phases, to start with the qualitative phase, the quantitative phase needs to be completed first.

The objective of the quantitative phase is to purposefully select the best participants for qualitative study. The qualitative phase has the objective of obtaining more information to help explain quantitative results (Hanson, Creswell, Clark, Petska, & Creswell, 2005).

Research Study Methodological Basis

This methodology is depicted in two phases: a quantitative phase at first and a qualitative to complement to first one. The initial phase starts with the literature review to set up the basis for the construction industry, prefabrication and outsourcing and vertical integration concepts from other industries.

With the information collected from the literature review, the next step is to combine the outsourcing and backwards integration literature review with the prefabrication and the construction industry. This step is fundamental because it will allow identification of key parameters that will be discussed in the following phases.

The quantitative phase is the first phase in this research. A survey instrument has been developed to identify the key parameters of prefabrication. The survey will be distributed among general contractors, subcontractors and other prefabricated companies.

After having identified the key parameters through the survey, experts will be interviewed to confirm the key parameters and identify additional important parameters. The tone of the interviews will be focused on identifying constraints and clarify certain results obtained from the previous quantitative phase. After the interviews are completed, all the collected information will be processed with the objective of identifying the key parameters.

Data Collection

The rationale for the selection of the explanatory sequential design approach was because of the combination of the attributes of the construction industry (focused on prefabrication) and manufacturing strategic management (focused on outsourcing and backwards integration). The following subsections will describe the two research processes and how they fit within the overall research framework.

Quantitative Data

The quantitative data for this dissertation will be used to identify some key parameters that need to be included in the analysis and to identify the best subjects to interview in the second phase at the same time. By using surveys, subcontractors, general contractors and other stakeholders will be asked for their professional opinion on the subject.

Qualitative Data

The qualitative data focuses on verifying and developing on the key parameters identified in the literature review and the quantitative phase plus some possible new findings that may come out as the interviews progress.

The interviews will be with experts identified in the previous phase, who have had professional experience with prefabrication in their projects. The interview method was selected because it allows debating and asking more follow up questions as the conversation flows.

The idea is to verify the findings and, if possible, generalize the conclusions by involving other groups different than prefabricators.

Delimitations of the Study

The delimitations made for this study include the following:

- This research only focuses on short-term contracts as an alternative for make or buy. Any other alternative like strategic alliances, equity alliances, joint ventures and parent subsidiary relationships are not included in this research.

- From the strategic management point of view, this research only focuses on short-term contracts referred as outsourcing. Short-term contracts are the typical relation between general contractors and subcontracts within the construction industry. All other types of short-term contracts are not part of this investigation (refer to Figure 2.8).
- This research is focused on vertical integration (only backwards). It does not intend to develop on alternatives for vertical integration such as taper integration, strategic outsourcing and other possible alternatives.
- This research does not contemplate any type of horizontal integration or analysis (diversification of offered products and services).
- The surveys will identify the key parameters and potential interviewees. The instrument's main objective is to measure the perception of construction professionals regarding prefabrication and their process to decide between buying/subcontracting or self-performing prefabricated components.
- The interviews will be with experienced professionals in prefabrication who were identified in the previous phase of the research. This is done to get specialized information and to develop the expert's opinion through follow up questions.

- During this study, neither key parameters nor its conclusions will be implemented in any way.

Limitation of the Study

Studying the business parameters for a construction company to decide between outsourcing (buying) and self-performing (making) by opening a new subsidiary dedicated to prefabrication is a difficult task.

The first limitation is the general market conditions. There are many social, cultural, financial, political, economic and ecologic factors that move construction. Based on these conditions the demand for construction services and products will be required.

Another limitation is the construction industry company relationships which are extremely complex. Many times projects include architects, engineers, specialty architectural and engineering consultants, owners, developers, sureties, general contractors, construction managers, subcontractors and governmental authorities.

Further limitations of this study can be related to the choice of target respondents for the survey and interviews.

Summary

This chapter outlined the basic methods and procedures to be used to collect data and analyze it. The process starts with the literature review to identify potential key parameters, which will be a part of the first phase of the research.

The identified potential parameters will then help develop a survey instrument to identify which of these parameters are the most important. The survey will also allow researchers to identify subjects to interview in the second phase based on their willing to participate and their experience with prefabrication in the construction industry.

To verify the results, from the quantitative phase, a new instrument will be developed based on interviews. Experts in different fields who were identified in the previous phase will participate in these interviews. Finally, the results will allow verifying if the research is accurate and reliable.

CHAPTER 4: SURVEY

Chapter 4 provides information on the results of the survey using the methodology described in Chapter 3. These results along with additional interviews were used for the developing a decision making tool detailed in the following chapter.

Based on the literature review, a questionnaire was developed to further study prefabrication. The questionnaire focused on the decision making processes between self-performing and outsourcing (subcontracting) the prefabrication activities in the construction industry. It also provided an opportunity to study current trends on prefabrication as well as opinions and experiences of contractors, subcontractors and other stakeholders in the construction industry who have had some experience with prefabrication during their professional career. The survey results were also compared to similar studies.

Surveying Instrument

The questionnaire survey was an online survey composed of 19 questions. The first three questions focused on the demographics of the surveyed professional and the specialty area of the firms where they work. These questions were multiple choice. The next section focused on prefabrication. There were seven questions focused on the participant's personal experience and eight questions focused on the firm's experience. The following questions focused on details of prefabrication, safety, restrictions, self-performing and outsourcing. There were multiple choice questions, open questions to explain some of the multiple choice answers, agree or disagree questions (scale 1 to 5) and 5 ranking questions. Question 19 was reserved for final comments, where the participants could add any comment regarding prefabrication, make a personal comment or clarify some of their answers.

The survey was sent by email to the participants on November 22nd, 2013. The respondents were asked to forward the email to other construction professionals as appropriate. Of the 32 email direct invitations, 27 respondents completed the surveys between December 2013 and January 2014. The complete survey is in Appendix A.

Surveying Procedure

Participants were selected from the industry and professional organizations related to prefabrication, such as general contractors, electrical and mechanical subcontractors, specialized suppliers and academic people with experience on the subject. The participants received an email invitation to fill in the survey and forward it to other experts if they considered that they could provide important information for the research. The email invitation can be seen as Appendix B.

Survey data was gathered using an online link provided by Qualtrics survey tool. The resulting data analysis varied depending on the data type for each question. Demographics of respondents and their firms were analyzed using descriptive analysis. The prefabrication section of the survey questions was analyzed using a combination of multivariable and descriptive analysis. The Qualtrics reports of the survey results are shown in Appendix C: Qualtrics Report.

Survey Results

4.1 Demographic Results

The first section of the survey provided demographic information. The objective of the first question of the survey was to determine respondent's years of professional experience.

"**Q1** How many years of professional experience do you have?
- Less than 5 years
- 5 to 10 years
- 11 to 15 years
- 16 to 20 years
- More than 20 years"

The responses for Question 1 are shown in Table 4.1, which shows the number of responses and the percentages. Out of the 27 responses, 24 respondents answered this question (88.9% response).

Table 4.1: Years of experience (n=24).

Answer	Response	%
Less than 5 years	3	13%
5 to 10 years	0	0%
11 to 15 years	4	17%
16 to 20 years	7	29%
More than 20 years	10	42%
Total	**24**	**100%**

Two fifths or 41% of respondents who answered this question indicated that had more than 20 years of professional experience; 29% had between 16 and 20 years; 17% between 11 and 15 years; 0% between 5 and 10 years; and 13% indicated they had less than 5 years of professional experience in construction as shown in Figure 4.1.

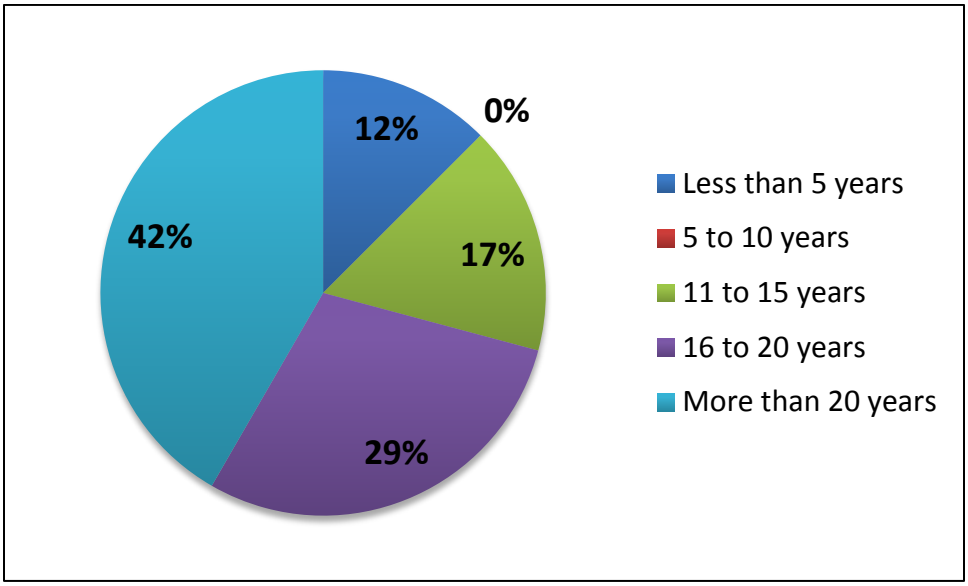


Figure 4.1: Years of experience (n=24).

4.2 Respondent's Firm Characteristics

This section shows results of the survey using descriptive analysis. Results are presented to show the characteristics of the firms where the respondents work.

Questions 2 and 3 look into the position of the firms within the construction industry. First by enquiring about the firms function in the vertical chain in the construction industry and then asking about the type of projects their firm mainly participate in.

> "**Q2** What describes the primary function of the company you work for in the construction industry?
> - ○ General Contractor
> - ○ Subcontractor
> - ○ Supplier
> - ○ PM Consultant
> - ○ Design and Engineering
> - ○ Other _____"

The survey was sent to experts in different fields including General Contractors (GCs) to specialized Subcontractors. The answer to this question identified the primary function of each respondent's company in the construction industry. The obtained answers are shown in Table 4.2. The table shows that out of a total of 27 respondents, 23 chose to answer this question (85.2%).

Table 4.2: Type of construction firm (n=23).

Answer	Response	%
General Contractor	12	52%
Subcontractor	4	17%
Supplier	0	0%
PM Consultant	1	4%
Design and Engineering	1	4%
Other:	5	22%
Total	**23**	**100%**

The primary functions are shown in Figure 4.2. A little over half of the respondents were General Contractors (52%); 17% of the respondents were subcontractors; no respondent was a supplier; Project Management Consultant and Design and Engineering had both the same number of responses (4% each); five respondents (22%) worked in a company with a different function than the ones mentioned in the survey question, among these were: Education, consulting, operator and a combination of other answers.

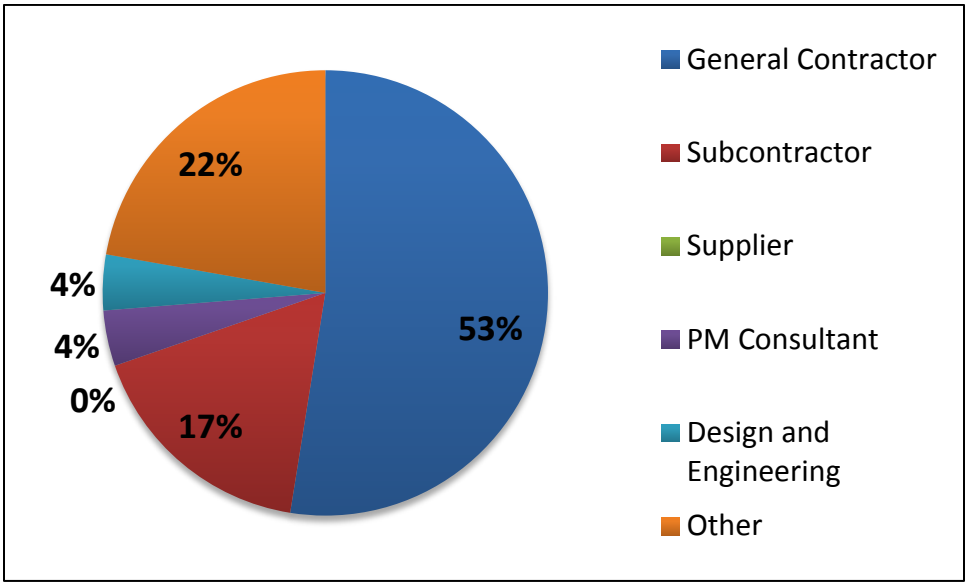


Figure 4.2: Type of construction firm (n=23).

"**Q3** What are the main type of projects your firm constructs?

- ☐ Residential
- ☐ Commercial
- ☐ Industrial
- ☐ Heavy civil
- ☐ Other: _____ "

Question 3 identified the main type of projects the respondent's firm constructs. The results are shown in Table 4.3 and Figure 4.3. This multiple choice question allowed the respondents to choose more than one option if they felt necessary. A total of 24 people responded to this question (88.9% response).

Table 4.3: Construction sector (n=24).

Answer	Response
Residential	2
Commercial	11
Industrial	16
Heavy civil (roads & bridges)	2
Other	3

Most of the respondent's firms construct industrial projects and commercial projects. Only a few indicated that their company constructs residential and/or heavy civil projects. Among the respondents who indicated "others"; responses included fields such as oil & gas, infrastructure, utility systems, tunneling, mining infrastructure, dams and hydroelectrics.

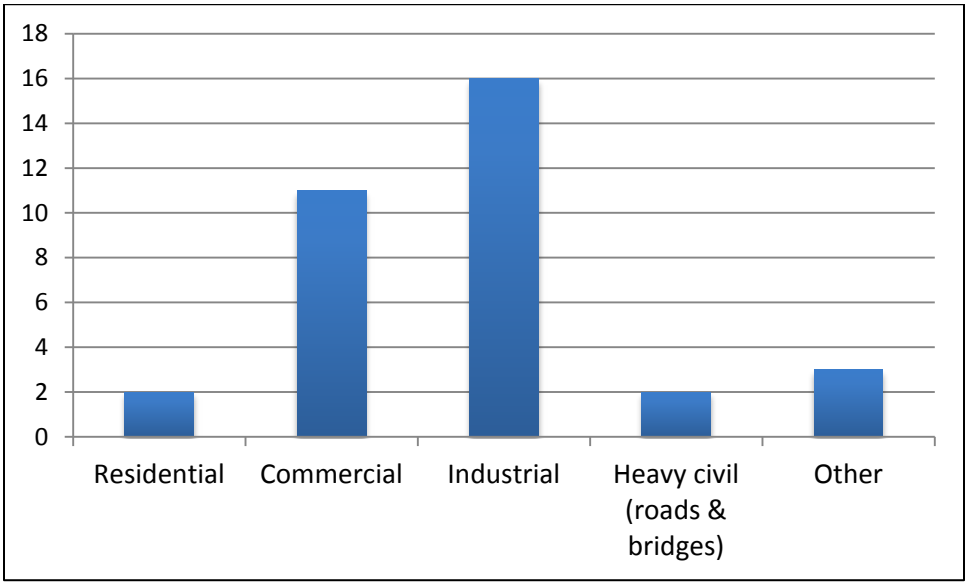


Figure 4.3: Construction sector (n=24)

4.3 Prefabrication Section

This section shows results of the survey using different analysis depending on the question. The prefabrication section includes two different types of questions, those regarding the respondent's personal experience and those concerning their firm. Table 4.4 shows how each question is grouped based on these two categories.

Table 4.4: Prefabrication questions of the survey.

Personal experience	Firm
Q4 Expectations for prefabrication for the construction industry	**Q5** Firm's experience with types of prefabrication
Q9 Respondent's direct participation in off-site prefabrication	**Q6** Firm's experience setting up prefabrication facilities
Q10 & **Q11** Self-prefabrication or subcontracting	**Q7** & **Q8** Safety procedures in prefabrication
Q16 Restrictions for using prefabrication	**Q12** & **Q13** Prefabrication division as a business opportunity
Q17 & **Q18** Reasons for subcontracting and self-performing	**Q14** & **Q15** Business Plan: subcontracting vs self-performing
Q19 Final comments	

4.3.1 Expectations for prefabrication for the construction industry

This section of the survey assessed the respondent's opinion regarding prefabrication. Question 4 asked the respondents to agree or disagree with two statements, based on a 1 to 5 scale in which 1 is strongly disagree and 5 is strongly agree.

> "**Q4** Do you believe that:
> - Prefabrication is a current trend applicable to your current projects.
> - Prefabrication can become a long term solution to improve construction performance"

The obtained results for both statements are shown in Table 4.5 and the responses on each statement are analyzed independently in the following lines.

Table 4.5: Obtained responses for question 4.

Question	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree	Total Responses
Prefabrication is a current trend applicable to your current projects	1	1	1	11	10	24
Prefabrication can become a long term solution to improve construction performance	1	1	2	6	13	23

As it can be seen in Figure 4.4, the level of agreement or disagreement regarding prefabrication as a current trend applicable to the respondents current projects show that there is a highly skewed distribution with most respondents agree that prefabrication can or could be employed in current projects.

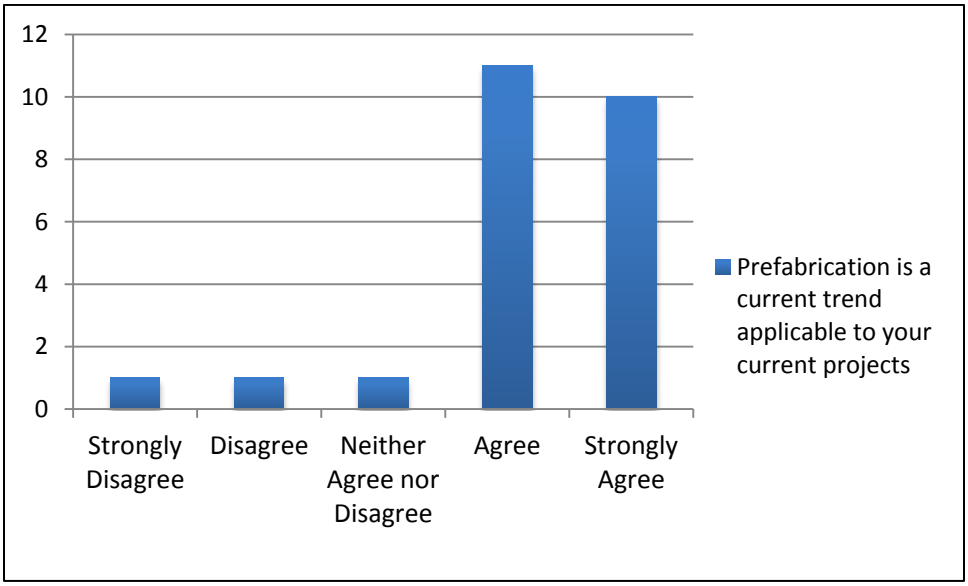


Figure 4.4: Level of agreement or disagreement to prefabrication as a current trend applicable to the respondent's current projects (n=24).

The statistic values for this question shown in Table 4.6 indicate a highly skewed with agreement that prefabrication can or could be currently employed in their current projects. This part of question 4 had 24 responses (88.9% response rate). The mean is 4.17 and the standard deviation is 1.01, this indicates that most respondents tend to Agree or Strongly Agree with the statement.

Table 4.6: Statistic values obtained from Table 4.5 (Qualtrics).

Statistic	Min Value	Max Value	Mean	Variance	Standard Deviation
Prefabrication is a current trend applicable to your current projects	1	5	4.17	1.01	1.01

Figure 4.5 shows the results for the level of agreement or disagreement regarding prefabrication as a long term solution to improve construction performance. It shows that there is a strong belief that prefabrication can become a long term solution to improve construction performance.

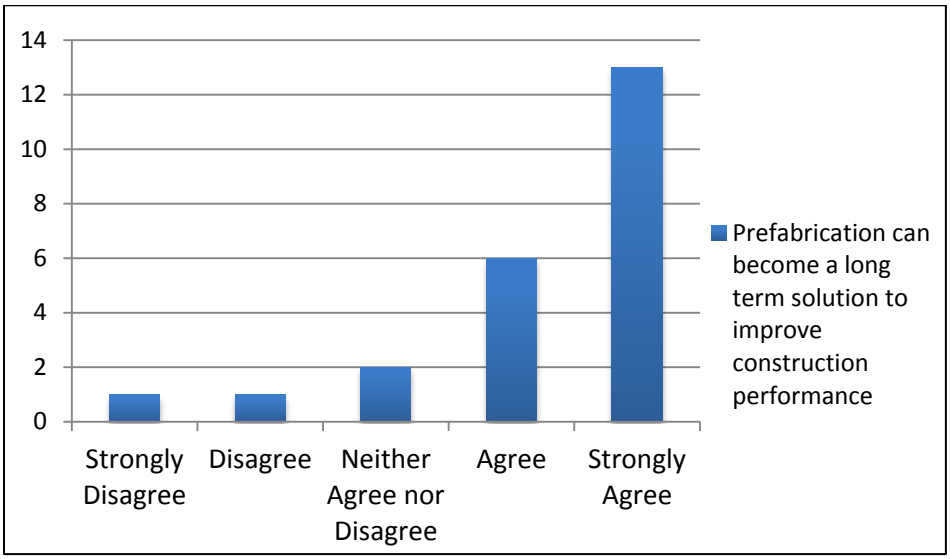


Figure 4.5: Level of agreement or disagreement to prefabrication becoming a long term solution to improve construction performance (n=23).

Statistical values of the previous question are shown in Table 4.7. The mean is 4.27 and a standard deviation of 1.1, indicate that most respondents tend to Strongly Agree with the statement that prefabrication can become a long term solution to improve construction performance.

Table 4.7: Statistic values obtained from Table 4.5 (Qualtrics).

Statistic	Min Value	Max Value	Mean	Variance	Standard Deviation
Prefabrication can become a long term solution to improve construction performance	1	5	4.26	1.2	1.1

Overall, these results match the report from the Board on Infrastructure and the Built Environment Division on Engineering and Physical Sciences National Research Council in 2009, when they considered prefabrication as one of the "Activities with Potential for Breakthrough" (CACPUCI, 2009); and also matches the expectations for the US market overview prepared in 2013 for the construction industry where they predicted that in the upcoming years, modularization and prefabrication will play an increasingly vital role in the entire construction industry (Bowman et al., 2013).

4.3.2 Firm's experience with types of prefabrication

This section of the survey assessed the firm's experience with prefabrication to determine if they mainly subcontract certain activities or self-perform them. Five activities were proposed with the option for the respondents to add up to two more activities. The question and the activities were:

"**Q5** What type of off-site construction/fabrication of building systems has your company performed?
- HVAC
- Wall Panels
- Precast
- Electrical
- Bathrooms
- Other: _____
- Other: _____"

The results of the survey for this question are shown in Table 4.8 and Figure 4.9. The number of responses for each question is shown in Table 4.8. The results of the survey for this question are shown in Table 4.9. The response rate for this question was 88.9%, but all of them responded only regarding the activities they knew about or performed in the past.

Table 4.8: Prefabricated systems performed by GC's and subcontractors (n=24).

Question	Performed by GC	Performed by Subcontractor	Total Responses
HVAC	3	12	15
Wall Panels	8	6	14
Precast	5	9	14
Electrical	1	13	14
Bathrooms	1	6	7
Other (a): structural steel, oil and gas modules, M&E modules and racks, plumbing	2	7	9
Other (b): Pipe racks, chillers	2	2	4

The bar graph in Figure 4.6 shows that, of all the proposed systems, HVAC, electrical and bathrooms tend to be executed mostly by subcontractors; Precast tends to be primarily performed by a subcontractor. A considerable percentage of GC's might also tend to perform the prefabrication of this system. Wall panels seem to be the only system in which GC's tend to prefabricate more than subcontractors.

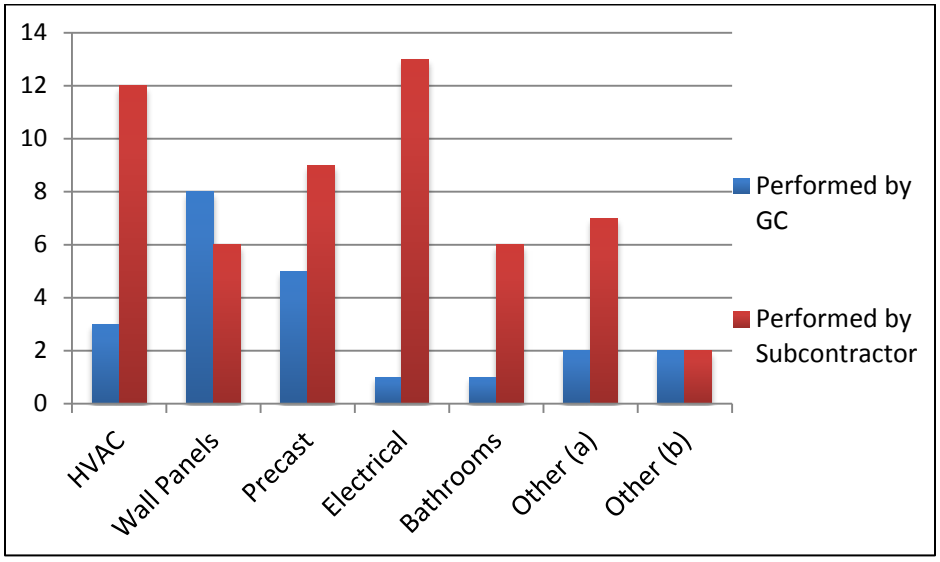


Figure 4.6: Prefabricated systems performed by GC's or Subcontractor (n=24).

Looking at the total responses for this question, the results are similar to the McGraw-Hill Construction study (Bernstein, 2011) which they studied the most commonly used prefabricated and modular building elements (Figure 4.7).

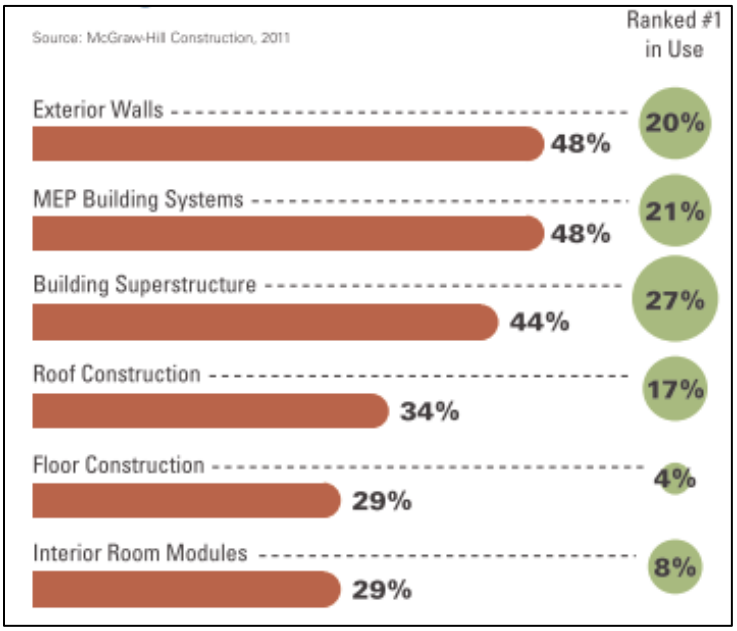


Figure 4.7: Most commonly used prefabricated and modular building elements (Bernstein, 2011)

The top three most commonly used prefabricated and modular elements are highly related between the two charts: HVAC and Mechanical, Building superstructure and precast concrete and exterior walls with wall panels. The differences may come from the different wording used in both studies, and the sample used which may have affected the results.

4.3.3 Firm's experience setting up prefabrication facilities

This section of the survey looked into the firm's experience of setting up prefabrication facilities. The objective of this question was to determine if this is a common practice in the construction industry. Question 6 asked the respondents:

> "**Q6** Has your company ever set-up a temporary facility to build prefabricated components?
> - Yes
> - No"

If the respondents answer was “No”, they were asked to skip questions 7 and 8. The response rate for this question was 88.9%. The results show that almost half of the people who responded this question work for a company that has set-up a temporary facility to build prefabricated components (Figure 4.8).

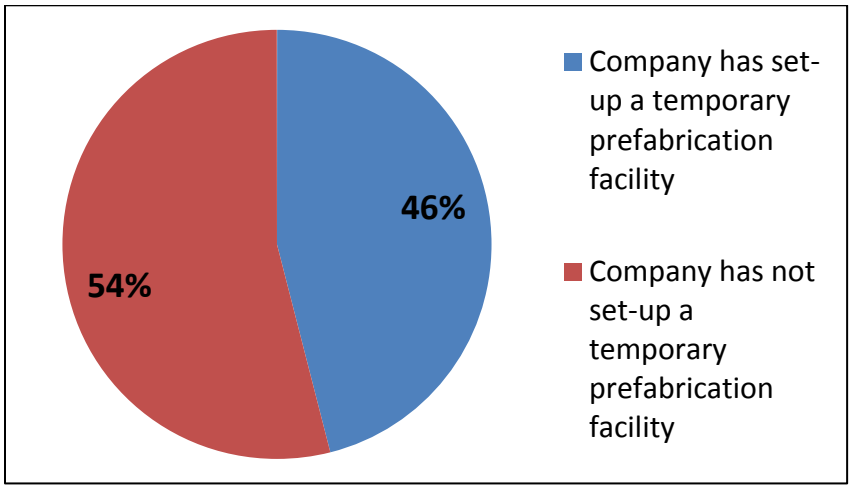


Figure 4.8: Experience setting-up a temporary facility to build prefabricated components (n=24).

These results are of interest when compared to the McGraw-Hill Construction study (Bernstein, 2011) where they studied the adoption of prefabrication and modular building processes among contractors. They concluded that, the “adoption of prefabrication and modular building processes is not a new activity for most contractors. 57% of contractors surveyed have been using these processes for five years or more” (Bernstein, 2011). Although it is not the same question, there are similarities among both results.

4.3.4 Safety procedures in prefabrication

Section 4.3.4 was included in the survey with the objective of studying safety procedures of those companies who have set up temporary facilities to build prefabricated components. The importance of this section of the research is that there are plenty of reports on the impact of prefabrication on site safety, but there is little on safety procedures on the off-site facilities.

Question 7 and 8 asked the respondents safety procedures in a temporary facility to build prefabricated components. Specifically, did handle safety procedures in the plant any different than what they did in the construction site and if they consulted or had experience with manufacturing safety principles.

> "**Q7** Was there a difference in how you handled the safety procedures of your temporary facility versus the construction site?
> - Yes
> - No
> - I don't know"

The results of the survey for these questions are shown in Figure 4.9. The response rate was 40.7% out of the total because this question was only available for the respondents who indicated that they did work for a company that has set-up a temporary facility to build prefabricated components in question 6.

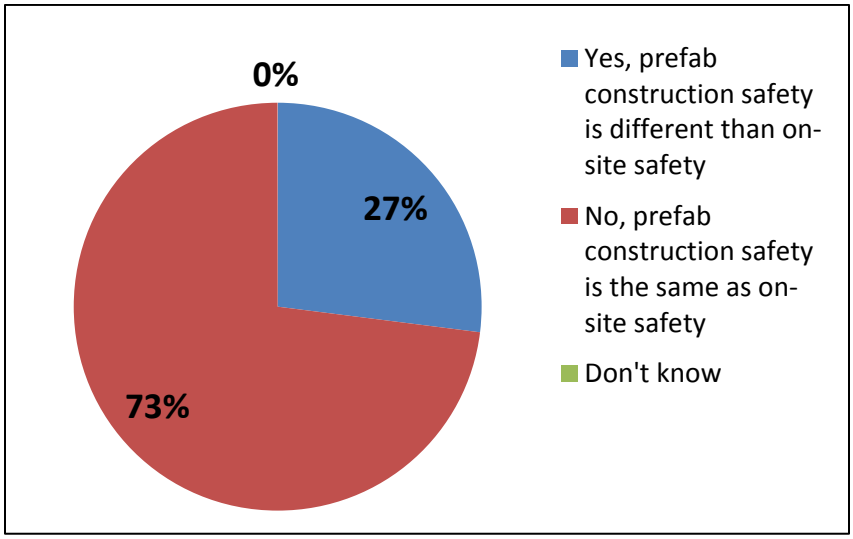


Figure 4.9: Differences in safety practices at the prefabrication site vs the construction site (n=11).

The results show that most of the companies that set up a temporary facility to prefabricate adopted the same safety procedures as if they were in a construction site. Similarly to question 7, Question 8 followed the safety topic in temporary prefabrication facilities by asking if the respondent knew if the firm consulted or had experience with manufacturing safety principles.

> "**Q8** Did you consult or have experience with manufacturing safety principles?
> - Yes
> - No
> - I don't know"

The results of the survey for these questions are shown in Figure 4.10. Similarly to question 7, the response rate was 40.7% for the same reason. The results show that a little over half of the respondents did not consult or had any experience with manufacturing safety principles at the time of the survey.

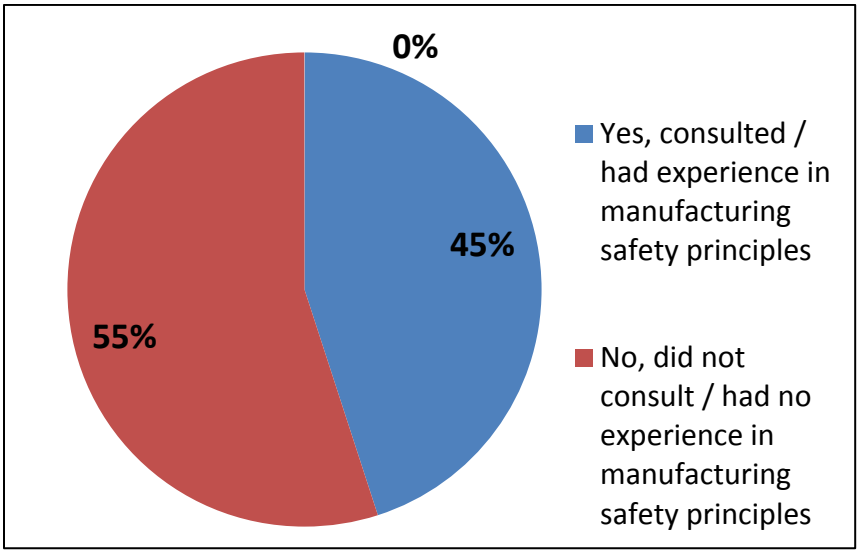


Figure 4.10: Companies with knowledge of manufacturing safety principles (n=11).

4.3.5 Respondent's direct participation in off-site prefabrication

Section 4.3.5 looked back into the respondent's experience by asking if they participated directly in off-site prefabrication of construction components.

Question 9 asked the respondents:

> "**Q9** Have you ever directly participated in the off-site prefabrication of construction components during your professional career?
> - Yes
> - No"

The results of the survey for this question are shown in Figure 4.11. The response rate was 88.9%. The results show that almost three quarters of the respondents had direct participation in setting up an off-site prefabrication plant during their professional career.

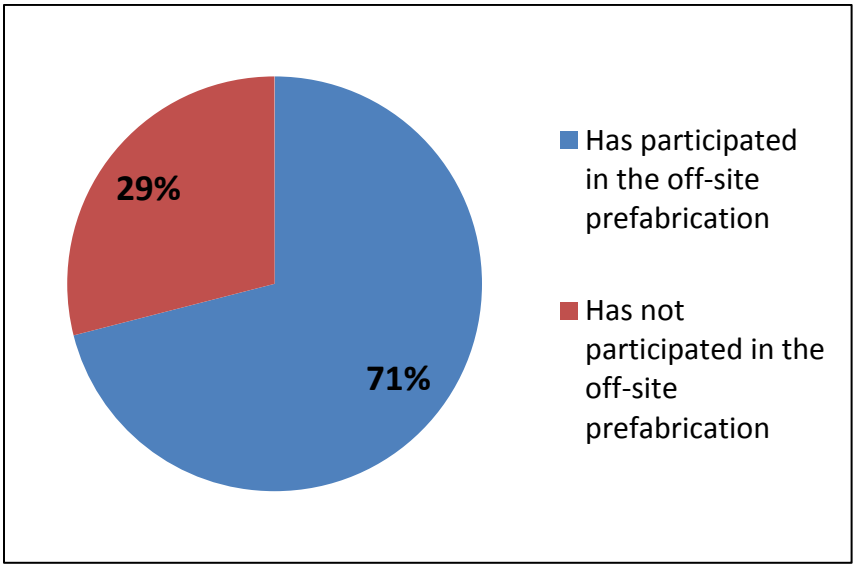


Figure 4.11: Professionals with experience in off-site prefabrication (n=24).

These results are close to the obtained information from the McGraw-Hill Construction study where they concluded that 85% of their respondents were users of prefabrication/modularization and 15% were not (Bernstein, 2011). The differences between both results may be caused by the biased sample, while the McGraw-Hill Construction study had a bigger sample (809 responses) that included general contractors, construction managers, mechanical contractors, electrical contractors, fabricators and design-builder/others; the present study had limited resources for the survey which ended up affecting the size of the sample.

4.3.6 Self-prefabrication or subcontracting

This section of the survey explored reasons for either outsourcing or self-performing prefabrication. Once a contractor of subcontractor is in a situation in which they have to use prefabrication, how do they decide between subcontracting the prefabrication or self-performing the prefabrication components.

The first question in this section asked respondents for their experience in the decision making between self-performing prefabrication activities or subcontracting the prefabricated components. This is accompanied by a follow up question asking for the reasons for the respondent's choice.

Questions 10 and 11 asked the respondents:

> "**Q10** When working or studying the use of prefabrication for your projects, did you consider opening a temporary facility to prefabricate the elements yourself or outsourcing the work?
> - Temporary facility
> - Outsource the work
> - Both
> - None"

The results of the survey for this question are shown in Table 4.9. The response rate was 88.9%.

Table 4.9: Decisions of opening a temporary prefabrication facility or outsourcing (n=24).

Answer	Response	%
Temporary facility	5	21%
Outsource the work	6	25%
Both	11	46%
None (Skip to Question 12)	2	8%
Total	24	100%

Figure 4.12 represents the distribution respondents who worked or studied the use of prefabrication for your projects and decided between outsourcing or self-performing

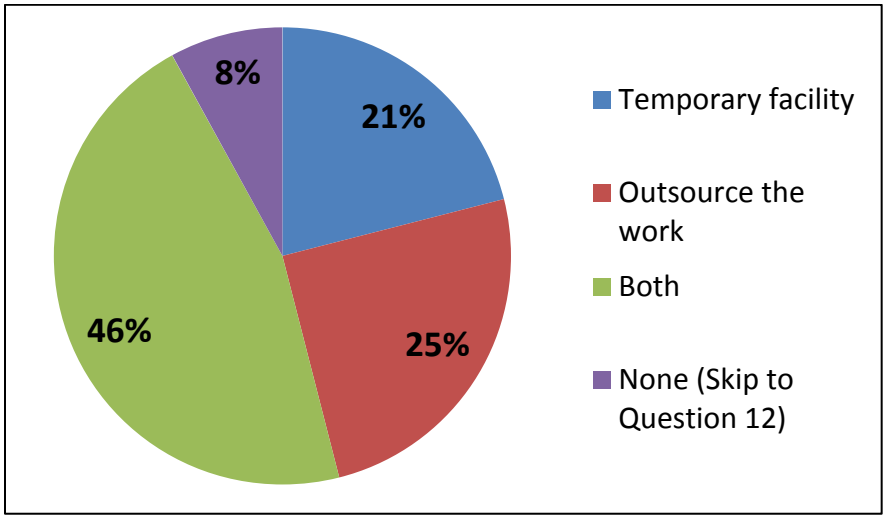


Figure 4.12: Decisions of opening a temporary prefabrication facility or outsourcing (n=24).

The results show that almost half of the respondents studied or considered both options (outsourcing and self—performing), one quarter considered outsourcing, almost a fifth of the respondents considered self-performing by setting up a temporary facility, and one tenth didn't study or consider any of the options. If the respondent answered "None", they were asked to skip question 11.

"**Q11** What were the reasons for your choice?"

This was an open follow up question with the objective of understanding what made the respondents choose between self-performing, outsourcing or both. This particular question had a low response rate, the response rate was 3.70%, which means that only one respondent answered this question. The only answer is presented in Appendix C - Question 11.

4.3.7 Prefabrication division as a business opportunity

This section of the survey was composed of two questions. It evaluated the respondent's opinion on setting up a division in a construction firm solely for prefabrication as a business opportunity. The questions accessed whether the firm should self-perform prefabrication activities or subcontract them. This is accompanied by a follow up open question asking for the reasons of the respondent's choice.

Questions 12 and 13 asked the respondents:

> "**Q12** Do you believe that setting up a division solely for prefabrication within your firm could be a new business opportunity for Construction Companies?
> ○ Yes
> ○ No"

Figure 4.13 represents the distribution of the respondents who believe that setting up a division solely for prefabrication in a construction firm could be a business opportunity. The response rate was 77.8%.

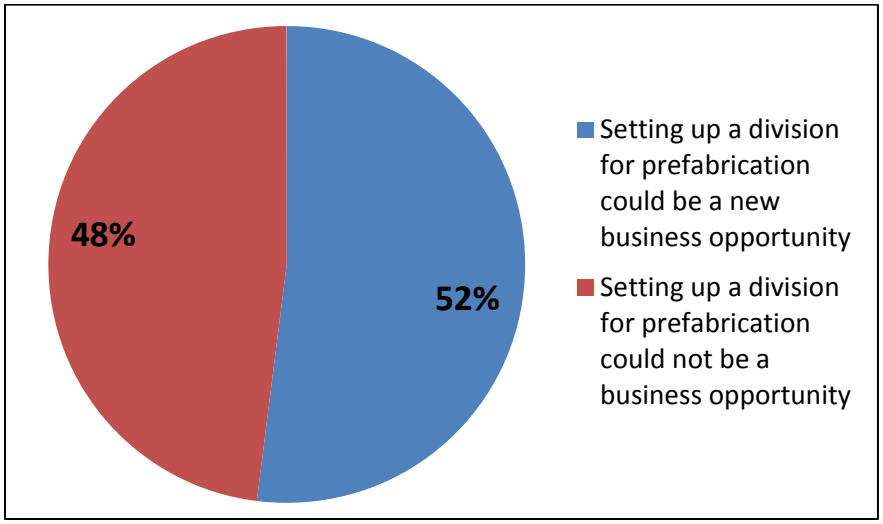


Figure 4.13: Opinions on setting up a division for prefabrication as a business opportunity (n=21).

The results show that a little over half of the respondents believe that setting up a division solely dedicated to prefabrication could be a new business opportunity for construction companies. As a follow up question, respondents were asked to explain their reasons why they thought a division dedicated to prefabrication may be a new business opportunity for construction companies:

> "**Q13** Please Explain:"

The results can be seen in Appendix C: Qualtrics Report. Out of the 27 respondents only 15 responded to this question (55.6% response rate). There were different responses stated that are presented in Appendix C - Question 13, but it can be summarized as follows:

Comments supporting setting up a division solely for prefabrication:

1. Prefabrication helps reduce the construction time and costs and improves productivity.
2. It may become a competitive advantage.
3. The reduced number of companies available in the market offers an opportunity for business.
4. Prefabrication helps improve the quality and safety in the construction projects.
5. The market allows to apply prefabrication if there are multiple projects and/or the projects are large enough.
6. Some companies have had good experiences prefabricating on their own.
7. Prefabrication is a self-supported business on its own.

Comments not supporting setting up a division solely for prefabrication:

1. It goes against the business plan of the firm.
2. It is not a current practice in the industry.
3. There is too much uncertainty in the market.
4. Outsourcing reduces costs.

4.3.8 Business Plan: subcontracting vs self-performing

This section of the survey examined the firm's experience on including changes in their business plan to move from subcontracting to self-performing more activities. The purpose was to analyze the current trends and experiences. The second question of this section was an open follow up question.

Questions 14 and 15 asked the respondents:

> "**Q14** Has your company developed a business plan that involves changing from subcontracting to self-performing more construction activities?
> o Yes
> o No"

Figure 4.14 represents the distribution of the respondents who work for a company that developed a business plan that involved a change from subcontracting activities to self-performing them. The response rate was 70.4%.

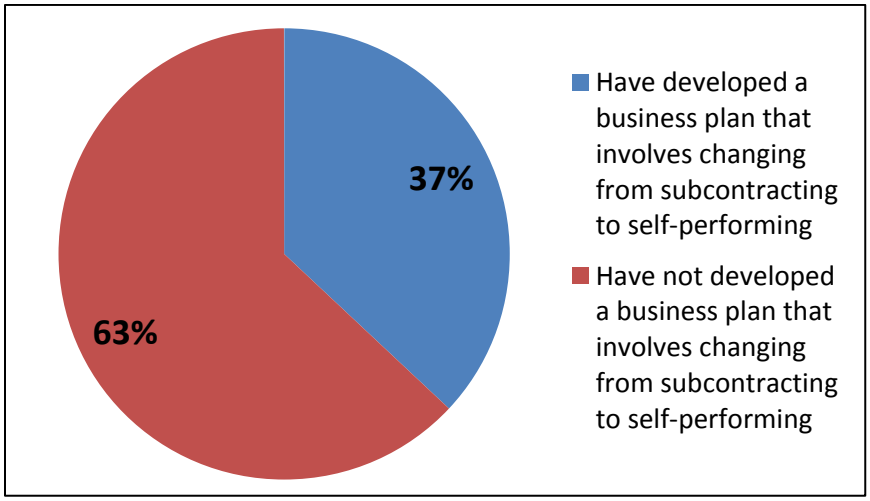


Figure 4.14: Companies that developed a business plan that involved changing from subcontracting to self-performing more activities (n=19).

The results show that a little over three fifths of the respondents work for a construction company that has not developed a business plan that considers changing from subcontracting to self-performing more construction activities. As an open follow up question, respondents were asked to explain their reasons why they thought the company considered changing from subcontracting to self-performing more activities:

"**Q15** Please Explain:"

The results can be seen in Appendix C – Question 15. Out of the 11 responses, seven indicated that in some way they have started self-performing some activities or started discussing it for different reasons such as a high demand that could not be satisfied by subcontractors or suppliers or to add more elements to their construction portfolio. One respondent indicated that they already outsourced everything. One respondent indicated that they did the opposite (moved from self-performing to outsourcing). The last two respondents had a neutral position towards this question.

4.3.9 Restrictions for using prefabrication

This section of the survey looked into the respondent's experience. They were asked to rank from 1 to 10 the most important restrictions to use prefabrication.

Question 16 asked the respondents:

"**Q16** According to your experience, please rank what you consider the most important restrictions to use prefabrication in your industry. Order from 1 to 10, being 1 the first restriction that you consider the most important and 10 the lease important.
_____ Very little or none integration between planning, design, manufacturing, supply and installation in the projects (1)
_____ Prefabricated projects are more expensive than traditional site-built projects (2)
_____ Lack or insufficient building codes to facilitate prefabrication (3)
_____ Considerable labor limitations on the job site (lack of skills, safety and/or quality knowledge) (4)
_____ Considerable labor limitations on prefabs plants (lack of skills, safety and/or quality knowledge) (5)
_____ Clients preference for on-site building (6)
_____ Limited capacity of other subcontractors to coordinate and perform with the prefabrication activities (7)
_____ Job site restrictions (8)
_____ Type of project (9)
_____ Other: (10)"

The results of the survey for this question are presented in Appendix C - Question 16. The response rate was 74.1% (20 respondents out of 27). Based on the position the respondents placed the restrictions, the restrictions were assigned with a score. If they considered that the restriction was the most important restriction (first position in their ranking list), the restriction would get 10 points; the second place on their list would get 9 points and so on. The least important restriction would get 1 point. Finally, the scores were averaged based on the number of respondents. Those ranked and averaged results are shown in Table 4.10:

Table 4.10: Result after processing the ranking of most important restrictions to use prefabrication.

Points	Restriction
6.29	Very little or none integration between planning, design, manufacturing, supply and installation in the projects
5.63	Type of project
5.29	Job site restrictions
4.83	Clients preference for on-site building
4.79	Considerable labor limitations on the job site (lack of skills, safety and/or quality knowledge)
4.79	Limited capacity of other subcontractors to coordinate and perform with the prefabrication activities
4.29	Lack or insufficient building codes to facilitate prefabrication
4.00	Considerable labor limitations on prefabs plants (lack of skills, safety and/or quality knowledge)
3.83	Prefabricated projects are more expensive than traditional site-built projects
2.08	Other

Figure 4.15 represents the scores after being ordered from highest to lowest. It shows that the integration between planning, design, manufacturing, supply and installation is the most important restriction to deal with in prefabrication. All the other restrictions have close scores, which indicates numerous restrictions have some importance.

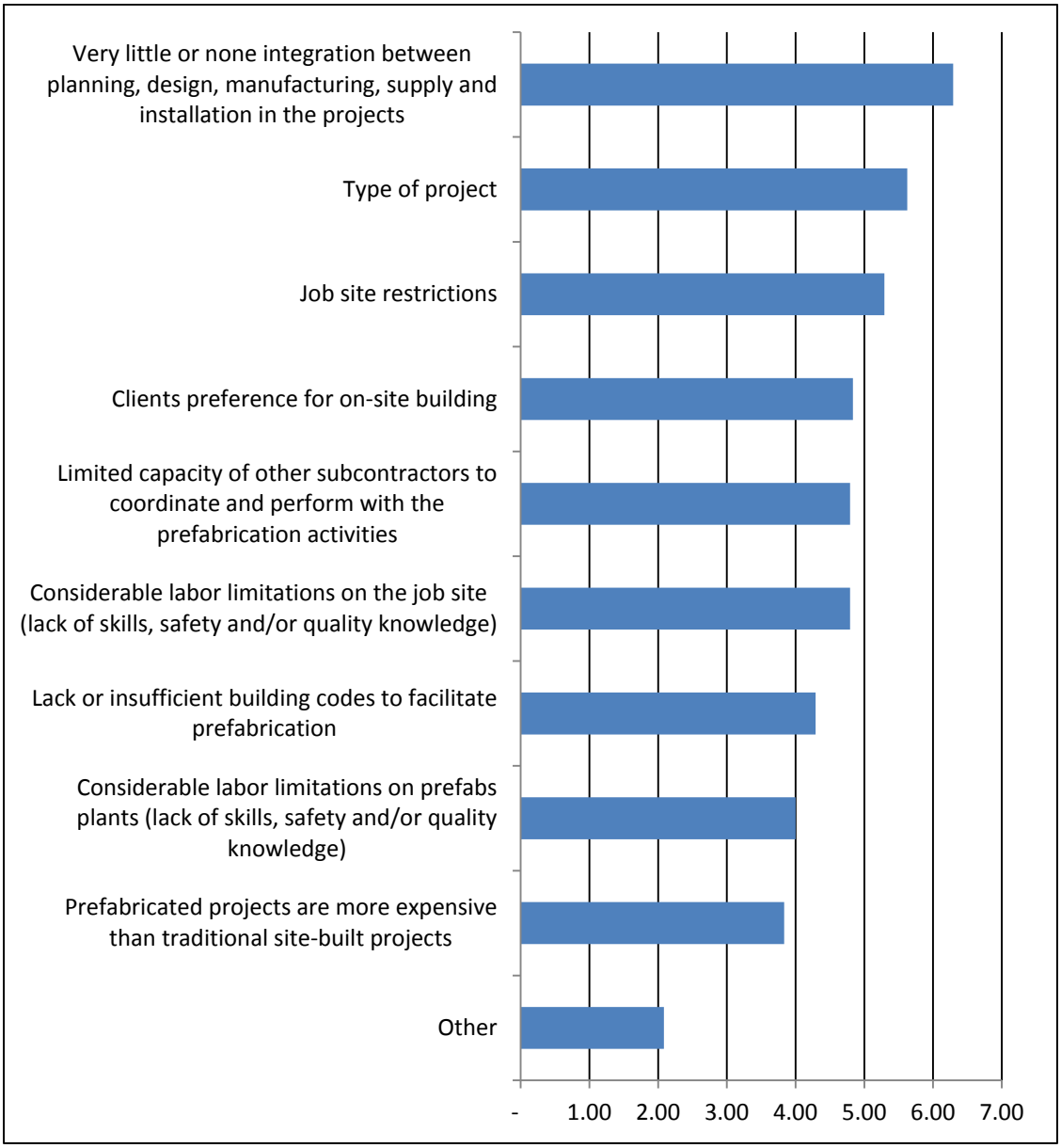


Figure 4.15: Ranking of most important restrictions to use prefabrication (n=20).

Among the restrictions included in the group “Other” there were new restrictions such as:

- Cost of modifications for the owner.
- Window for changes is shorter.
- Union considerations.
- Equipment and facilities for prefabrication.
- Lack of knowledge of what can be prefabricated.

A chart of a similar study of reasons for not using prefabrication/modularization on projects is shown in Figure 4.16 (Bernstein, 2011).

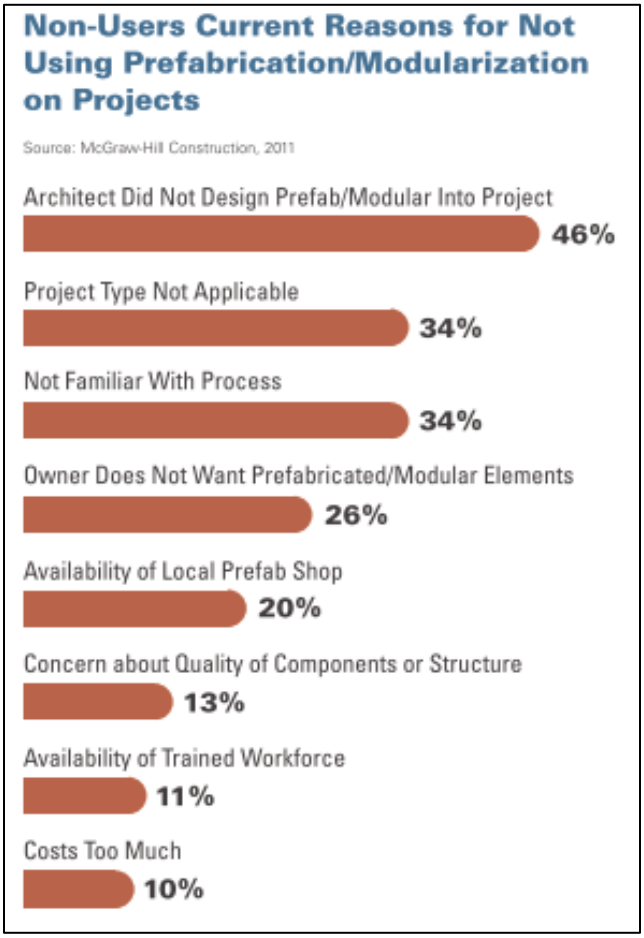


Figure 4.16: Non-Users reasons for not using prefabrication/modularization on projects (Bernstein, 2011)

By comparing this chart with the survey results, it is observed that the first two top reasons or restrictions match, there is an important restriction on the design part of the construction projects and the applicability based on the type of project. The other important match is the fourth restriction that is related to the client's preferences to on-site building.

4.3.10 Reasons for subcontracting and self-performing

This section was composed by two open questions in which the respondents were asked to list up to five reasons to self-perform the prefabrication activities and up to five reasons to subcontract them.

Questions 17 and 18 asked the respondents:

> "**Q17** Provide and rank five (05) reasons for subcontracting or buying prefabricated components from a different firm:
> (1) _____
> (2) _____
> (3) _____
> (4) _____
> (5) _____"

The results can be seen in Appendix C: Qualtrics Report. There were different responses stated in different ways, but out of the 16 responses (59.3% response rate), the reasons were grouped into 14 categories and then counted to find the frequency they were mentioned by the respondents. The results are presented in Table 4.11:

Table 4.11: Reasons for outsourcing prefabrication activities (n=24).

Reasons	Frequency
Subcontracts are specialized and have better control of the Know-how	11
Less construction cost	7
Fast Delivery / Schedule effective	5
Number of projects / workload / personnel rotation	4
Established site location	4
Less risk	4
Subcontractors already have the resources / facilities	3
Projects require less qualified staff and overhead	2
Reduced production capacity	2
Safety	2
Subcontractors have the capacity to stock	1
Subcontractors have to compete	1
Better quality / Warranty	1
Allows GC's to focus on main business	1

Figure 4.17 represents the Pareto graph showing the frequencies and percentages after being grouped, counted and ordered from highest to lowest. It shows that “subcontracts are specialized and have better control of the Know-how” is the most important factor for construction firms to outsource prefabrication activities. This reason is followed by a “less construction cost”, the “fast delivery and schedule effectiveness”, the “number of projects, workload and personnel rotation”, having an “established site location” and “less risk” for the GC. The other reasons although they are important, according to Pareto’s rule are not so relevant (the last 20%).

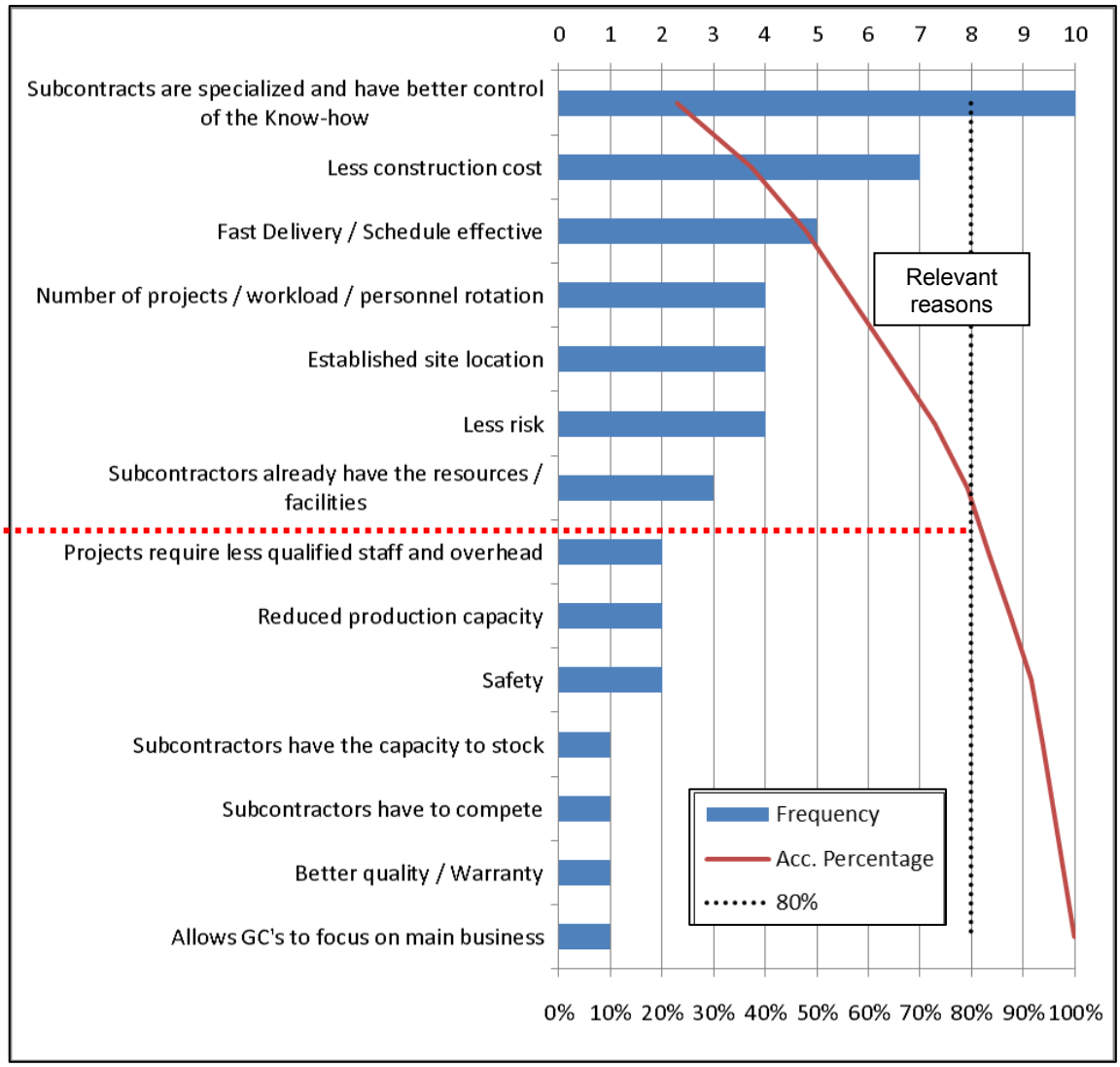


Figure 4.17: Pareto graph of the most important reasons for outsourcing prefabricated activities (n=24).

"**Q18** Provide and rank five (05) reasons for self-performing prefabricated components:
(1) _____
(2) _____
(3) _____
(4) _____
(5) _____"

The results can be seen in Appendix C: Qualtrics Report. There were different responses stated in different ways, but out of the 16 responses (59.3% response rate), the reasons were grouped into 14 categories and then counted to find the frequency they were mentioned by the respondents. The results are presented in Table 4.12:

Table 4.12: Reasons for self-performing prefabrication activities (n=24).

Reasons	Frequency
Better control over quality, safety, logistics and schedule	12
Prefabrication helps stabilize the workload and labor	7
Reduces costs and enhances profitability	6
Know-how stays in the company	4
Reduces risks by involving less parties	3
Reduce variability and improves planning	3
Less competitors / Competitive advantage	2
Capacity to work on customized prefabricated elements	2
Less problems with unions	2
Complements or replaces the subcontractors / suppliers with low capacity	1
Projects allow use of prefabrication	1
Reduce construction time	1
Allows innovation	1
Improvement in communication	1

Figure 4.18 represents the Pareto graph showing the frequencies after being grouped, counted and ordered from highest to lowest. It shows that having a better control over quality, safety, logistics and schedule is the main reason for construction firms to self-perform prefabrication activities. This reason is followed by how prefabrication helps stabilize the workload and labor of a construction firm, how it also reduces costs and enhances profitability and that by self-performing, the know-how stays in the company, it reduces risks by involving less parties and also reduces variability and improves planning. The other reasons although they are important, according to Pareto's rule are not so relevant (the last 20%).

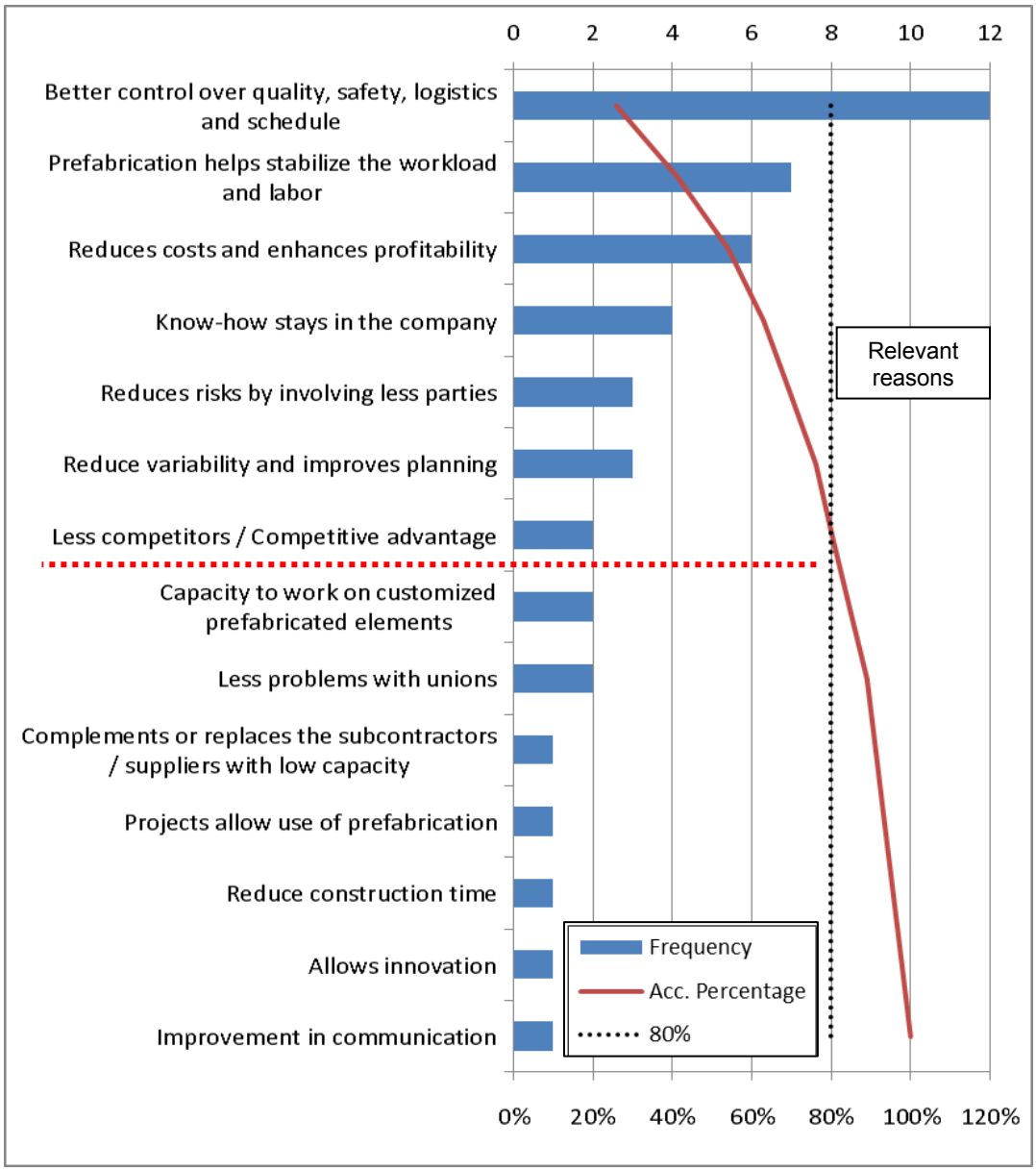


Figure 4.18: Pareto graph of the most important reasons for Self-performing prefabricated activities (n=20)

4.3.11 Final comments

Finally, the last section asked the respondents if they had any comments regarding prefabrication, the survey or any related topic to the research.

Question 19 asked the respondents:

"**Q19** Final Comments:"

The results of the survey for this question are diverse and the respondents commented on different topics such as problems understanding a question to their personal experience in the construction industry and what they believe may be the future of prefabrication and the construction industry.

The original comments can be seen in Appendix C: Qualtrics Report. Out of the 27 respondents, this question had six responses (22.2% response rate). To summarize the comments, they were grouped in different categories, considering that this was an open question, one answer could fit more than one group at the same time:

Problems with questions:

- Problems understanding question 16.

Current conditions and challenges to use prefabrication:

- "Prefabrication philosophy is not new but it seems to have taken on renewed interest".
- Outside of non-competitive national oil companies, "modular works are considered more often".

- The “disdain for modular jobs” is in the special realities that the owner ends up with.
- “Challenges exist in renovation projects or in areas where union jurisdictions conflict”.
- Prefabrication is “a huge, mostly untapped opportunity to advance the use of technology and quality in our industry”.

Requirements to use prefabrication:

- “Each Project should be evaluated from early stages (design) about the possibility of using precast”.
- If a contractor gets an already designed Project, “a value engineering process should also be carried out in order to decide on prefabrication”.

Future of prefabrication in the construction industry:

- Future for construction “may be in prefabrication”.
- Respondents believe that research in this area at this time is quite applicable to the Construction Industry.
- Respondents think that “the trends will gear themselves toward more prefabrication in the future continuing with hotels, condos, prisons and box stores”.

- As the prefabrication trend catches on, “manufacturing plants will grow to support the industry”.

Decision making between subcontracting and self-performing:

- “The decision whether to subcontract or self-perform should always be evaluated as an option, based on the resources, know-how, and experience on previous projects”.

CHAPTER 5: DECISION PROCESS FOR SELECTING MANUFACTURING PRACTICE FOR PREFABRICATED CONSTRUCTION COMPONENTS

In this chapter the process of developing a decision making tool for the construction industry is detailed. The decision making tool is intended for companies that are starting to look into prefabrication as a possible business opportunity and are trying to decide if it is better for them to self-perform the prefabricated components or if it is more convenient to outsource the components. The tool was tested and approved utilizing interviews with professionals with experience and knowledge on prefabrication and who were not a part of the survey so that their responses on the tool was not biased towards their own answers. The decision making tool developed is shown in Appendix D through G.

Decision making tool development objective and target

The first step to develop the too was to set up a clear target and objective. The tool is targeted to companies that are accessing prefabrication as a possible business opportunity. The firms are evaluating if it is better for them to self-perform the prefabricated components or if it is more convenient to outsource components to another firm. The objective of the tool is to assist companies with

their decision making process based on company information such as business plan, growth expectations and company policies.

Information analysis

Chapter 3 presented important findings and trends in prefabrication. The chapter also provided new information concerning outsourcing and self-performing prefabricated components and prefabrication as a business opportunity, which according to the survey is currently being analyzed at construction companies. Also, as noted in Chapter 3, there were two core questions in the survey:

1. The top five reasons for self-performing prefabricated components.
2. The top five reasons to outsource prefabrication.

Since both questions were open ended, there were no similar answers. Therefore there was an additional process for these two questions which involved sorting them into similar topics, counting responses and identifying relevant reasons. Pareto's theorem was used to assist in identifying the relevant reasons.

Regarding the reasons to outsource, of a total of 48 individual reasons, they were sorted into 14 categories based on similar of answers and related topics. Given 14 categories, it was possible to make a count and then sort them for a Pareto. Seven relevant categories which would be used for the decision making tool. A similar process was used for reasons to self-perform and six relevant categories were determined which would be used for the decision making tool.

Analytical Hierarchical Process (AHP)

The AHP is a decision process developed by Thomas Saaty. This method is used for decision making when there are more than one alternative and they need to be evaluated with respect to multiple criteria (Saaty, 1982). The AHP has been widely used in engineering analysis, and was recently used in the analysis of crane safety (Shapira & Simcha, 2009) and to assess concrete saws with silica dust reduction equipment (Hubbard, Middaugh, Zimmerman, & McGlothlin, 2009).

The AHP methodology is simple and straightforward; it does not require specialized software or other specialized knowledge or tools. The method requires break down of the problem into elements, which can be discretely assessed by utilizing weighted factors for each criteria (Hubbard et al., 2009). This methodology will work well to asses and assist construction companies to choose between self-performing or outsourcing the prefabricated components for their projects.

The first step in translating a decision into the AHP framework is to describe the required decision and relevant factors (already identified in the analysis of the survey results – Questions 17 and 18) by breaking the situation down into different criteria. The criteria must be general enough to describe the problem, and in some cases it is appropriate to elaborate on criteria by providing sub-criteria (Saaty, 1982).

Each of the selected criteria will provide the foundation for quantitative valuation of the alternative solutions for the stated problem. In order to compare each alternative with respect to all the criteria, a weighting factor is used to indicate the relative priority of the criteria. There are multiple ways in which the weighting factors can be determined, for example, weighting factors might be based on expert opinion, paired comparisons, or on a statistical analysis of each criterion's impact on outcome (although it is unusual to have reliable statistical data for most problems) (Hubbard et al., 2009). In this case, the weighted factors will be based on the results obtained from the surveys.

Adapting the AHP method for two different evaluations

One of the main characteristics of the AHP is that it compares two or more alternatives with the same criteria. However, for the decision making tool based on the results from the survey, there were different reasons for construction companies to adopt either self-performing or outsourcing the manufacturing of the prefabricated components. These reasons would be considered as criteria, but since both alternatives have different reasons it is not possible to compare directly one to the other in a direct AHP using the results of the survey.

For this reason, the AHP was adapted for two different sets of criteria, one set is only for self-performing and the second set is only for outsourcing. After prioritizing, and weighting all the values, each alternative will receive a final score. This final score is comparable between the two alternatives. And finally by comparing the two scores the tool will be able to indicate which alternative might be the most suitable for the construction firm based on their business plan and company policies.

Construction of the decision making tool

This section of the chapter explains in detail how the decision making tool was constructed based on the results obtained from the survey, the AHP method and the AHP adaptation explained in the previous section.

The tool was created using a Microsoft Office Excel application and was developed from the results obtained from the surveys. The construction and reasoning behind the development of each section of the tool is explained in Figure 5.1.

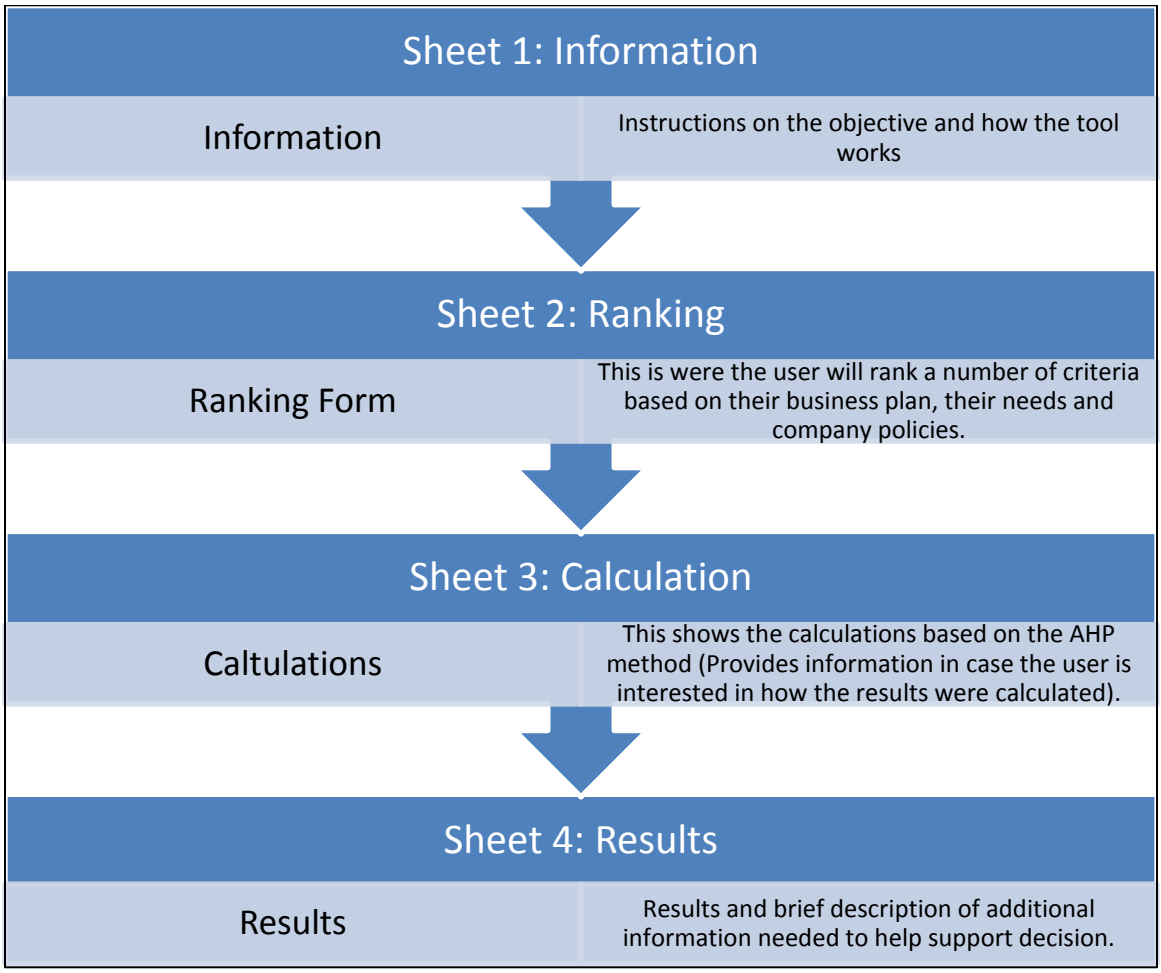


Figure 5.1: Explanation of the four sheets in the decision making tool between self-performing and outsourcing the manufacturing of prefabricated components based on Prasad Chennupati (2013).

Decision making tool

The decision making tool is composed of four Microsoft Excel sheets utilizing Macro functions. In these sheets there are instructions, variables, scoring and formulas that will be further explained in this section.

Parameters

As mentioned before, there were seven relevant reasons for outsourcing and six relevant reasons for self-performing according to the results obtained from the surveys. When studying the thirteen parameters it resulted in an inordinate amount of data to rank for the users. To solve this issue, parameters were grouped together. Table 5.1 shows the "reasons for outsourcing" and how they were grouped together into four parameter for the final decision making tool.

Table 5.1: Grouping relevant reasons as parameters for outsourcing for the decision making tool.

Parameters for outsourcing	
Risk reduction	Reduce construction cost by reducing job overhead and labor
	Share the risks with other parties
Front End Schedule Control	Have Fast Delivery of prefabricated components / Schedule effective
Stabilize Workload Across Company	Number of projects / workload / personnel rotation
Strong Relationships with Subcontractors that can prefabricate components	Established site location
	Subcontractors are specialized and have better control of the Know-how
	Subcontractors already have the resources / facilities

In a similar way, the reasons for self-performing were grouped together into four parameters. Table 5.2 shows the way they were grouped.

Table 5.2: Grouping relevant reasons as parameters for self-performing for the decision making tool.

Parameters for self-performing	
Control of Quality, Safety, and Schedule	Have better control over quality, safety, logistics and schedule
	Reduce risks by involving less parties
Enhance profitability	Reduce costs and enhances profitability
Protection of intellectual property and core competencies	Keep the know-how in the company
Onsite resources Optimization	Stabilize the workload and own labor of the projects
	Reduce variability and improve planning

With the grouping of parameters from the two major categories, eight (08) parameters remained to be ranked by the user:

For outsourcing:

1. Risk reduction:

   This refers to the reduction of the contractor's risk. Some examples are:

   - Sharing/transferring risks with other parties.
   - Reducing overhead.
   - Reducing skilled labor on site.

2. Front End Schedule Control:

   This refers to the reduction and control the projects schedule by:

   - Not needing time to set up a facility prior to the start of a project.
   - Design does not need to be completed prior to construction.

3. Stabilize Workload Across Company:

   This refers to the company workload depending on:

   - Unknown forthcoming projects.
   - Long term staffing needs.

4. Strong Relationships with Subcontractors that can prefabricate components:

   Construction firms have relationships with:

   - Highly skilled prefabrication subcontractors.
   - Subcontractors with sufficient facilities, labor and equipment.

<u>For self-performing:</u>

1. Control of Quality, Safety, and Schedule:

   This refers to contractors having:

   - Better Control of Quality, Safety, and Schedule.
   - More control of project logistics.
   - Fewer subcontractors.

2. Enhance profitability:

   This refers to the reduction of the contractor's objective to:

   - Reduce costs.
   - Increase their profits.

3. Protection of intellectual property and core competencies:

   This refers to the reduction of the contractor's wanting to keep specific know-how in the company.

4. Onsite resources Optimization:

   This refers to contractors wanting to optimize the use of company labor and improve planning.

These are the eight parameters that have to be prioritized by the users when they rank which options are more important for their firms.

Weighting

The weighting of each parameter is based on the results from the survey. It depends on the number of times the reasons were mentioned in the surveys (Points column in Table 5.3 and Table 5.4). The group points are the sum of the times individual reasons were mentioned in the surveys. Finally, the weight is a percentage of the group points compared to the total group points. Table 5.3 shows the weighting for outsourcing.

Table 5.3: Weighted values for each outsourcing parameter to be ranked by the user

Reasons for Outsourcing		Points	Group Points	Group %
Risk reduction	Reduce construction cost by reducing job overhead and labor	7	11	28.95%
	Share the risks with other parties	4		
Front End Schedule Control	Have Fast Delivery of prefabricated components / Schedule effective	5	5	13.16%
Stabilize Workload Across Company	Number of projects / workload / personnel rotation	4	4	10.53%
Strong Relationships with Subcontractors that can prefabricate components	Established site location	4	18	47.37%
	Subcontractors are specialized and have better control of the Know-how	11		
	Subcontractors already have the resources / facilities	3		

The weight for self-performing is shown in Table 5.4.

Table 5.4: Weighted values for each self-performing parameter to be ranked by the user

Reasons		Points	Group Points	Group %
Control of Quality, Safety, and Schedule	Have better control over quality, safety, logistics and schedule	12	15	42.86%
	Reduce risks by involving less parties	3		
Enhance profitability	Reduce costs and enhances profitability	6	6	17.14%
Protection of intellectual property and core competencies	Keep the know-how in the company	4	4	11.43%
Onsite resources Optimization	Stabilize the workload and own labor of the projects	7	10	28.57%
	Reduce variability and improve planning	3		

Total score calculations

Based on the weighting factors from the surveys and the rankings input by the users, the spreadsheet will perform all the calculation on sheet 3 (Calculations). The first step will be scoring each parameter based on the rank provided by the user. The possible scores go from 1 to 8, 1 as the most important reason in the ranking. The most important reason will get the highest possible score (eight points). The second most important reason will get seven points and so on until the least important (ranked 8th in the ranking sheet), this one will get the least amount of possible points (one point).

After scoring the parameters based on the users ranking, they will be multiplied by the weight factors and finally summed together for final scores; one final score for outsourcing and one final score for self-performing. These final scores are comparable to each other and will be the ones that determine the final result to support the company's prefabrication decision. Table 5.6 shows the calculations for outsourcing as an example on how the system works.

Table 5.5: Example of calculations for outsourcing.

Outsourcing					
Reasons	**Ranked**	**Score**	**Group scores after factors**	**Total score**	**Percentage**
Risk reduction	2	7	2.03	4.05	46%
Front End Schedule Control	4	5	0.66		
Stabilize Workload Across Company	5	4	0.42		
Strong Relationships with Subcontractors that can prefabricate components	7	2	0.95		

Table 5.6 follows the same example for self-performing.

Table 5.6: Example of calculations for self-performing.

Self-Performing					
Reasons	**Ranked**	**Score**	**Group scores after factors**	**Total score**	**Percentage**
Control of Quality, Safety, and Schedule	6	3	1.29	4.71	54%
Enhance profitability	3	6	1.03		
Protection of intellectual property and core competencies	8	1	0.11		
Onsite resources Optimization	1	8	2.29		

The last column in Tables 5.5 and 5.6 represent the percentage of the total score of self-performing plus the total score for outsourcing. These percentages are used to provide a graphical comparison in the results sheet of the Microsoft Excel document.

Total Scores and comparisons

As mentioned before, the total score is the sum of the weighted group scores. Each alternative (self-performing and outsourcing) will get a total score that is comparable. To assist in visualizing the comparison, the results sheet will show a gauge that shows to the left self-performing and outsourcing to the right. The arrow indicates a firm's inclination to either outsourcing or self-performing.

Decision making tool walkthrough

This decision making tool begins with an information sheet. The instructions sheet contains the objective, the target users and basic information on how to use the decision making tool (Figure 5.2). Clicking on the Ranking Form button it will take the user to the ranking form (Sheet 2). This portion of the spreadsheet utilizes Macro programing in M.S. Excel.

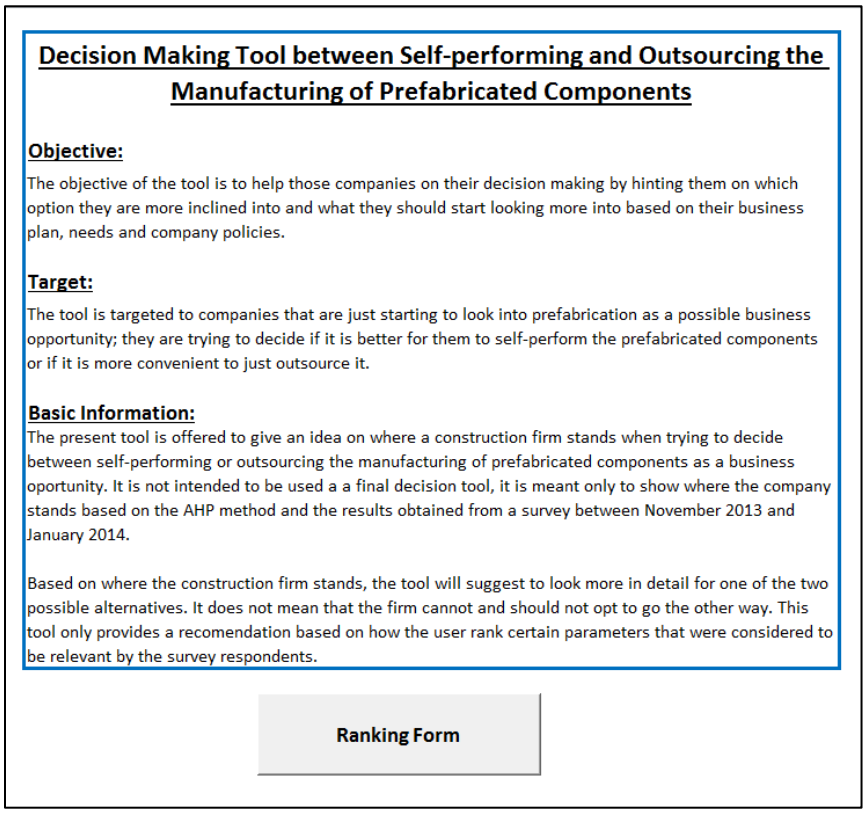


Figure 5.2: View of the information sheet.

Sheet 2 contains the form that the user will use to rank the order of importance according to your company's needs and requirements for prefabricating components. Being 1 the most important and 8 the least important (Figure 5.3). The user may do one of four things:

1. Go back to the Information sheet (sheet 1) by clicking on the “Home” button.
2. Reset ranking if the user completed the rank but then decides to start all over may click on the button “Reset Ranking”, this will delete all the ranking done so far and will take the user to the top of the page.
3. Show calculations if the user wishes to see how the calculations are done, the user may click on the button “Show Calculations tab” (sheet 3).
4. Process rank if the user wishes to see the final result, the user may click on the button “Process Rank”. This will take the user to the results tab (sheet 4).

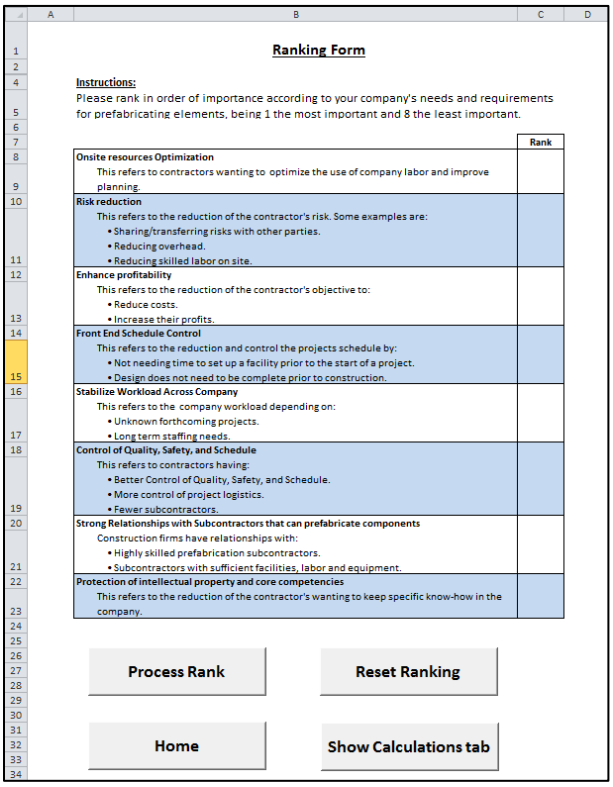
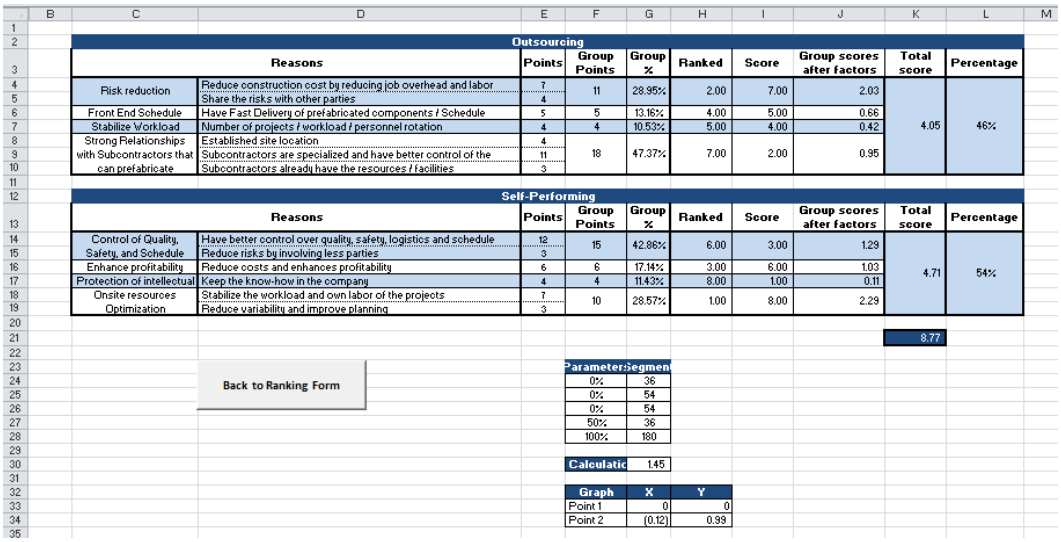


Figure 5.3: View of the ranking sheet.

Sheet 3 provides all the calculations preformed based on the parameter ranking in sheet 2 (Ranking). This third tab is for information only, if the users choose to not see this sheet, they may skip it and go straight to the results. The Calculations sheet shows from row 2 to row 21 all the calculations to get the total score for outsourcing and the total score for self-performing and the final percentages comparing both scores (column L). Between cell F23 and cell H34 are the calculations used to draw and operate the gauge which assists in visualizing the comparison with the arrow that indicates a firm's inclination to either outsourcing or self-performing the manufacturing of their prefabricated components. Finally, The calculations provides a button for the user to go back to the Ranking sheet as shown in Figure 5.3.



Outsourcing

Reasons		Points	Group Points	Group %	Ranked	Score	Group scores after factors	Total score	Percentage
Risk reduction	Reduce construction cost by reducing job overhead and labor	7	11	28.95%	2.00	7.00	2.03	4.05	46%
	Share the risks with other parties	4							
Front End Schedule	Have Fast Delivery of prefabricated components / Schedule	5	5	13.16%	4.00	5.00	0.66		
Stabilize Workload	Number of projects / workload / personnel rotation	4	4	10.53%	5.00	4.00	0.42		
Strong Relationships with Subcontractors that can prefabricate	Established site location	4	18	47.37%	7.00	2.00	0.95		
	Subcontractors are specialized and have better control of the	11							
	Subcontractors already have the resources / facilities	3							

Self-Performing

Reasons		Points	Group Points	Group %	Ranked	Score	Group scores after factors	Total score	Percentage
Control of Quality, Safety, and Schedule	Have better control over quality, safety, logistics and schedule	12	15	42.86%	6.00	3.00	1.29	4.71	54%
	Reduce risks by involving less parties	3							
Enhance profitability	Reduce costs and enhances profitability	6	6	17.14%	3.00	6.00	1.03		
Protection of intellectual	Keep the know-how in the company	4	4	11.43%	8.00	1.00	0.11		
Onsite resources Optimization	Stabilize the workload and own labor of the projects	7	10	28.57%	1.00	8.00	2.29		
	Reduce variability and improve planning	3							

8.77

Back to Ranking Form

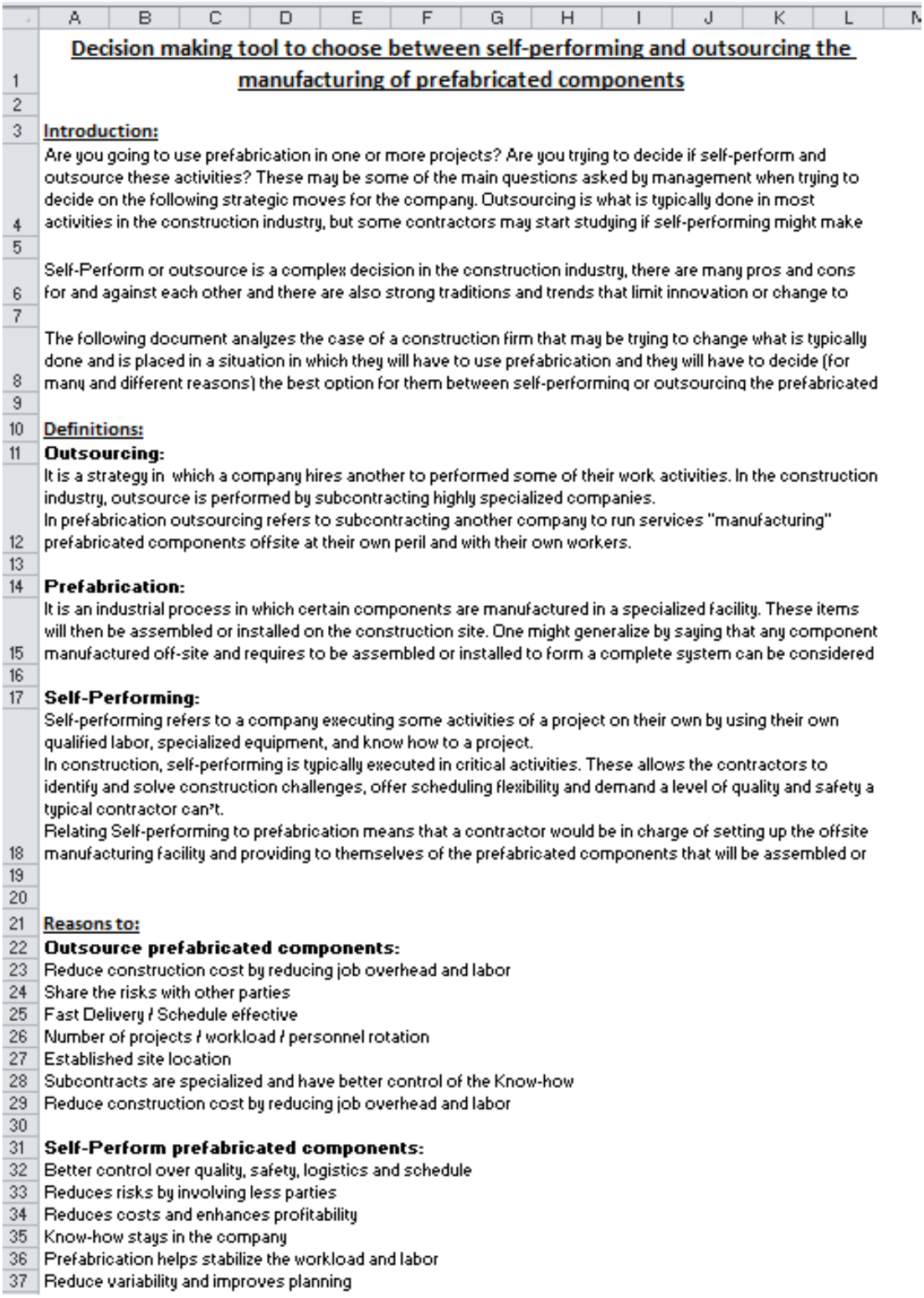
Parameter	Segment
0%	36
0%	54
0%	54
50%	36
100%	180

Calculatic	1.45

Graph	X	Y
Point 1	0	0
Point 2	(0.12)	0.99

Figure 5.4: View of the calculations sheet.

Sheet 4 will show the user the results based on the ranking. The first part will provide the users with general information, definitions and reasons to outsource and reasons to self-perform based on the literature review of this thesis and the results obtained from the surveys. Figure 5.5 shows the first part of the results sheet.



Decision making tool to choose between self-performing and outsourcing the manufacturing of prefabricated components

Introduction:

Are you going to use prefabrication in one or more projects? Are you trying to decide if self-perform and outsource these activities? These may be some of the main questions asked by management when trying to decide on the following strategic moves for the company. Outsourcing is what is typically done in most activities in the construction industry, but some contractors may start studying if self-performing might make

Self-Perform or outsource is a complex decision in the construction industry, there are many pros and cons for and against each other and there are also strong traditions and trends that limit innovation or change to

The following document analyzes the case of a construction firm that may be trying to change what is typically done and is placed in a situation in which they will have to use prefabrication and they will have to decide (for many and different reasons) the best option for them between self-performing or outsourcing the prefabricated

Definitions:

Outsourcing:

It is a strategy in which a company hires another to performed some of their work activities. In the construction industry, outsource is performed by subcontracting highly specialized companies.
In prefabrication outsourcing refers to subcontracting another company to run services "manufacturing" prefabricated components offsite at their own peril and with their own workers.

Prefabrication:

It is an industrial process in which certain components are manufactured in a specialized facility. These items will then be assembled or installed on the construction site. One might generalize by saying that any component manufactured off-site and requires to be assembled or installed to form a complete system can be considered

Self-Performing:

Self-performing refers to a company executing some activities of a project on their own by using their own qualified labor, specialized equipment, and know how to a project.
In construction, self-performing is typically executed in critical activities. These allows the contractors to identify and solve construction challenges, offer scheduling flexibility and demand a level of quality and safety a typical contractor can't.
Relating Self-performing to prefabrication means that a contractor would be in charge of setting up the offsite manufacturing facility and providing to themselves of the prefabricated components that will be assembled or

Reasons to:

Outsource prefabricated components:

Reduce construction cost by reducing job overhead and labor
Share the risks with other parties
Fast Delivery / Schedule effective
Number of projects / workload / personnel rotation
Established site location
Subcontracts are specialized and have better control of the Know-how
Reduce construction cost by reducing job overhead and labor

Self-Perform prefabricated components:

Better control over quality, safety, logistics and schedule
Reduces risks by involving less parties
Reduces costs and enhances profitability
Know-how stays in the company
Prefabrication helps stabilize the workload and labor
Reduce variability and improves planning

Figure 5.5: View of the general information of the results sheet

Finally, the same sheet will show at the bottom of the page the results and a graphic representation on how much the user's firm is inclined to self-perform or outsource the manufacturing of the prefabricated components. Below the graph there is a button to take the user back to the Ranking sheet.

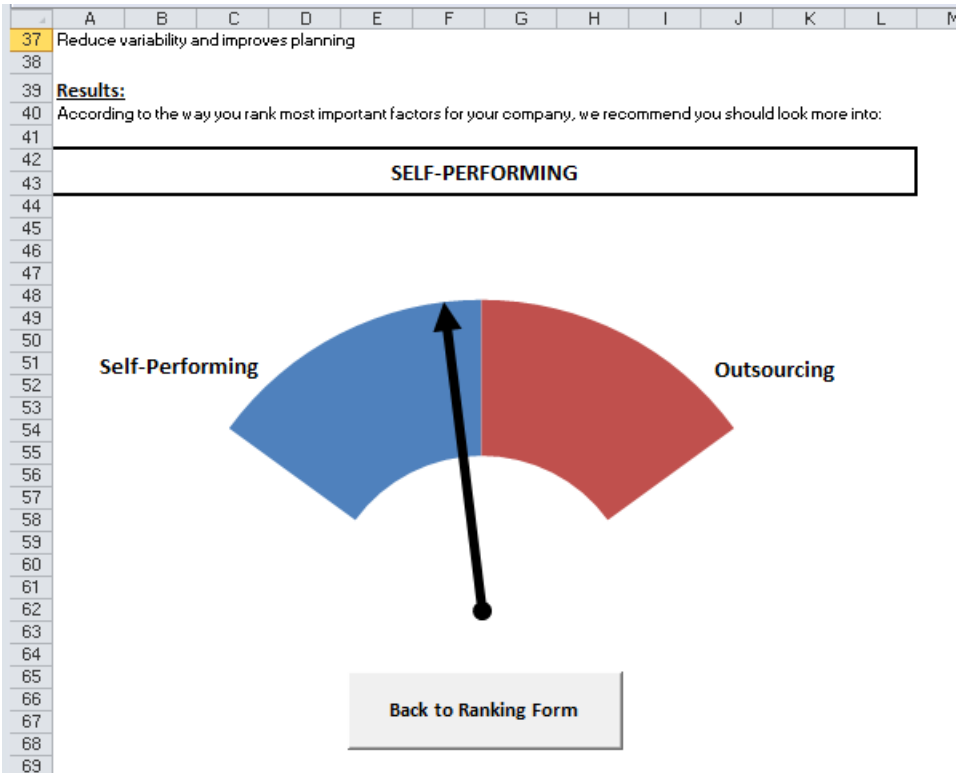


Figure 5.6: Gauge to show graphically the user where does the user's firm stands on self-performing versus outsourcing the manufacturing of prefabricated components.

Confirming the decision process with experts input

After the decision making tool was completed, it was presented to construction professionals who were not a part of the survey to avoid getting biased feedback towards their answers in the surveys. The interviews were performed with two construction professionals that had experience and/or knowledge on prefabrication.

Interviewee 1

Interviewee 1 has an important position in the board of directors of his construction firm. His firm is an important South American company that develops projects design, development, preparation and exploitation of mines and their subsequent implementation. He currently carries an important position in the chamber of construction for his country and makes presentations on the construction conditions and development.

Interviewee 2

Interviewee's 2 career started providing consulting services in change management and training for Fortune 500 corporations. Interviewee 2 worked in industry as part of the Operations Management team that managed the manufacturing of oil and gas equipment. Currently, Interviewee 2 is the VP in Learning and People Development in an important North American construction company. This professional also facilitates the continuous improvement of the company's Lean Operating System. Interviewee 2 is highly involved with the American General Contractors Association (AGC).

Comments of interviewees

Both interviewees were interested in the results and were briefed on how the tool was developed. As industry experts they considered it was a good tool but also had a few observations which were adopted in the final version:

1. The version both of them reviewed did not have the introduction sheet. Interviewee 1 suggested that to improve presentation of the document it should include a front page as the first page showing general information and limitations of the tool. This suggestion was adopted.
2. Both interviewees did not agree with the term “level” (Ranking sheet), they though it was too academic and since it was a tool for the industry it should have another term. The term “level” was changed to “balanced”.
3. Interviewee 2 suggested blocking the Ranking sheet in order that no parameter could have the same ranking level by the user. On the other hand, Interviewee 1 liked that he could rank more than one parameter in the same level because he considered them equally important, and did not mind because the ranking score would be finally affected by the weight factors. As a result, the Ranking sheet was not blocked, allowing the users to rank more than one parameter in the same order of importance.

4. Interviewee 1 did not agree with the risk reduction (outsourcing parameter) description where it was stated that there was a reduction on the job overhead. He stated that he did not see the overhead as a risk. He explained that by having less people in the staff there were less risks of miscommunication and the responsibilities were transferred to someone else (by outsourcing). He maintained his position and did not agree with that statement. This parameter was not modified because the tool was developed based on the results of the survey.
5. Both interviewees were confused between workload and resources balances. The interviewees thought that both workload terms referred to the same type of workload (as number of projects in construction). The terms were modified from the original “Balance Workload on Project” to “Onsite resources Optimization“. “Stabilize workload across company” was not changed in the tool.
6. Finally, interviewee 2 suggested protecting the cells in the Calculations sheet so that the users could not alter the formulas unintentionally. The Calculations sheet was not protected because it is intended to keep developing with future research in the similar matter, by keeping it unprotected it will allow any user to improve the tool as they consider necessary.

CONCLUSIONS

This study has identified key parameters for a construction company to decide between self-performing and outsourcing the manufacturing of prefabricated components for their project. The research studied and analyzed the current trends on prefabrication as well as opinions and experiences of contractors, subcontractors and other stakeholders in the construction industry who have experience with prefabrication. This chapter presents the final analysis and discussion of the results based on the results presented in previous chapters. This chapter also discusses the future research opportunities on related subjects that could be performed.

Prefabrication is known as a technique to have many benefits in the construction industry. It offers clear advantages in terms of project schedule, quality, and safety. Prefabrication and modular construction are processes that have been used by generations of construction professionals in different forms and in different areas of usage. Constructions professionals have used prefabrication for all different types of construction projects such as commercial buildings, industrial construction, heavy civil construction, and residential among others. There is a clear consensus among the construction professionals that prefabrication is a trend applicable to their projects, and also can become a long term solution to improve construction performance. Based on the survey from

this research 46% of the respondents indicated that their company has set-up a facility to build prefabricated components; 71% of the respondents indicated that they have directly participated in the off-site prefabrication of construction components during their professional careers; and almost half of the respondents considered that setting up a division solely for prefabrication within their firms could be a new business opportunity.

As with any construction technique, prefabrication has some important restrictions that need to be analyzed before applying. The four most important ones are:

1. Construction projects are not typically design to use prefabrication.
2. Types of projects in which prefabrication is not applicable.
3. Job site restrictions (size, traffic, logistic planning, additional loading risks).
4. Client's preferences to construct their projects on-site.

When a construction firm decides to use prefabrication, they have two options, they may self-perform or outsource (subcontract) the prefabricated components. According to the survey results, almost half of the respondents studied or considered both options (outsourcing and self—performing). One quarter of the respondents considered outsourcing and almost a fifth of the respondents considered self-performing by setting up a temporary facilities.

Within a building, prefabrication is used in a variety of areas but most often is performed by subcontractors for HVAC systems, precast elements,

electrical systems and bathrooms. Exceptions to this are the prefabricated wall panels, which are typically performed by general contractors.

When trying to decide between self-performing and outsourcing (subcontracting) the prefabricated components, construction companies may find different reasons to opt for one over the other. According to the results of this research, the most important reasons for a construction firm to outsource prefabrication are:

- Risk reduction by sharing and transferring risks with other parties, reducing overhead and reducing skilled labor on site.
- Front end schedule control, which means that there is a reduction and improvement in the control of the project's schedule by not needing time to set up a facility prior to the start of a project and the design does not need to be complete prior to construction.
- Stabilize workload across company, which means that the construction company does not have to worry about the workload of their projects and the prefabrication plant at the same time
- Strong relationships with subcontractors that can prefabricate components may ensure sufficient facilities, highly skilled labor and equipment for prefabricating components.

The most important reasons for a construction firm to self-perform prefabrication are:

- Having better Control of Quality, Safety, and Schedule; more control of project logistics and planning by having fewer subcontractors involved.
- Enhance profitability by reduce costs and/or increasing their profits.
- Protection of intellectual property and core competencies (keeping specific know-how in the company).
- Onsite resources optimization by adjusting and balancing the use of company labor and improving the planning.

Decision making tool

The decision making tool developed in this research was based on an extend literature review on the construction industry, prefabrication and self-performing and outsourcing theories. Using all the information as a base, a survey tool was developed, tested and forwarded to experts to fill. The results of the survey were processed and analyzed in order to create a decision making tool to assist construction companies in their decision to whether outsource or self-perform refabricated components.

The tool is focused on construction companies who have had some experience with prefabrication in the past and are currently trying to decide if they should open a prefabrication facility to self-perform their own prefabricated components or if they should outsource them. The tool is intended to provide an answer on the company's tendencies toward self-performing or outsourcing their prefabricated components based on the key parameters identified in the survey and ranked by the firm. It is not intended to give a definite answer on which process they should adopt. It is intended to provide feedback on important parameters they should consider in their decision process.

Future research

The potential of prefabrication studies and decision making in the construction industry are vast and diverse. This research could be expanded and further explored in many directions, including the following:

a. When should a construction company consider Horizontal Integration (diversifying).
b. Combining vertical integration and diversification in a construction company.
c. Other outsourcing versus self-performing studies within construction (different than prefabrication).

d. If a construction company choses to open a prefabrication facility, which safety parameters should they adopt from the manufacturing industries and which are the ones they should keep from the construction industry.
e. Further study of the decision making between opening a temporary prefabrication facility versus a permanent prefabrication facility.
f. Analysis of the Return on Investment (ROI) on self-performing prefabricated components.
g. The important connection of prefabrication with BIM modeling, LEED and Lean Construction.
h. Follow up research on the prefabrication restrictions, especially on the “No integration between Planning, design and construction”.
i. The level of use of prefabrication based on the construction company size.
j. A study of the impact on reducing on-site resources because of prefabrication.

REFERENCES

REFERENCES

Abdullah, F. (2004). *Construction industry and economic development: the Malaysian scene* (p. 138). Johor: Penerbit UTM.

American Society for Quality (ASQ). (2013). History of Quality. Retrieved from http://asq.org/learn-about-quality/history-of-quality/overview/overview.html

Ankrah, N. A., Proverbs, D., & Debrah, Y. (2009). Factors influencing the culture of a construction project organization An empirical investigation.pdf. *Engineering, Construction and Architectural Management*, *16*(6), 573–597. doi:10.1108/09699980911002584

Arif, M., & Egbu, C. (2010). Making a case for offsite construction in China. *Engineering, Construction and Architectural Management*, *17*(6), 536–548. doi:10.1108/09699981011090170

Bakens, W. (1992). Future Organization of the Building Process: Interim Results of a W82 Study Project. *CIB*.

Barthorpe, S., Duncan, R., & Miller, C. (2000). The pluralistic facets of culture and its impact on construction facets of culture. *Property Management*, *18*(5), 335–351.

Benner, M. J., & Tushman, M. L. (2013). Exploitation, Exploration, and Process Management: The Productivity Dilemma Revisited. *Academy or Management Review*, *28*(2), 238–256.

Bernstein, H. M. (2011). *Prefabrication and Modularization: Increasing Productivity in the Construction Industry*. (E. Fitch, Ed.) (p. 56). Bedford, MA: Mcgraw-hill Construction.

Bowman, J., Clancy, M., Giggard, R., Hoover, S., Hughes, J., Isaacs, S., … Warner, P. (2013). *Construction Overview* (p. 75). Raleigh, North Carolina. Retrieved from http://www.abc.org/Portals/1/Documents/CheifEconomist/FMI 2013 Forecast.pdf

Bureau of Economic Analysis (BEA). (2012). *Growth in Goods and Services Industries Slowed in 2011 Revised Statistics of Gross Domestic Product by Industry for 2009-2011* (p. 9).

Chiang, Y.-H. (2009). Subcontracting and its ramifications: A survey of the building industry in Hong Kong. *International Journal of Project Management*, *27*(1), 80–88. doi:10.1016/j.ijproman.2008.01.005

Confederation of International Contractor's Associations (CICA). (2010a). *GDP of each Region 2003-2010* (Vol. 2010, p. 1).

Confederation of International Contractor's Associations (CICA). (2010b). *Turn-Over of the Construction Industry of each Region 2003-2010* (Vol. 2010, p. 2). Retrieved from http://www.cicanet.com/images/stories/statistics/turnover.pdf

Construction Industry Institute (CII). (1992). *Automated Decision Support for Modular Construction* (p. 30). Austin.

Construction Industry Institute (CII). (2004). *Prefabrication, Preassembly, Modularization, and Offsite Fabrication in industrial Construction: A Framework for Decision Making* (p. 48).

Creswell, J. W. (2009). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches* (3rd ed., p. 260). Lincoln: Sage Publications Ltd.

Duggirala, M., Rajendran, C., & Anantharaman, R. N. (2008). Provider-perceived dimensions of total quality management in healthcare. *Benchmarking: An International Journal*, *15*(6), 693–722. doi:10.1108/14635770810915904

Egbu, C. O., Botterill, K., & Bates, M. (2001). A conceptual framework for studying knowledge management in project -based environments. *Proceedings of the 1st International Conference on Postgraduate Research in the Built Environment*, 186–195.

Forbes, L. H., & Ahmed, S. M. (2011). *Modern Construction Lean Project Delivery and Integrated Practices* (p. 490). Dayton, Ohio: Taylor and Francis Group, LLC.

Gibb, A. G. F. (1999). *Off-Site Fabrication* (p. 262). Loughborough: Whittles Publishing Services.

Gibb, A. G. F. (2001). Standardization and pre-assembly- distinguishing myth from reality using case study research. *Construction Management and Economics*, *19*(3), 307–315. doi:10.1080/01446190010020435

Gibb, A., & Isack, F. (2003). Re-engineering through pre-assembly: client expectations and drivers. *Building Research & Information*, *31*(2), 146–160. doi:10.1080/09613210302000

González-Díaz, M., Arruñada, B., & Fernández, A. (2000). Causes of subcontracting: evidence from panel data on construction firms. *Journal of Economic Behavior & Organization*, *42*(2), 167–187. doi:10.1016/S0167-2681(00)00084-6

Grant, R. M. (2008). *Contemporary Strategy Analysis* (6th ed., p. 482). Malden, MA : Blackwell Pub.

Hanson, W. E., Creswell, J. W., Clark, V. L. P., Petska, K. S., & Creswell, J. D. (2005). Mixed Methods Research Designs in Counseling Psychology. *Journal of Counseling Psychology*, *52*(2), 224–235. doi:10.1037/0022-0167.52.2.224

Hass, C., O'Connor, J. T., Tucker, R. L., Eickmann, J. A., & Fagerlund, W. R. (2000). Prefabrication and Preassembly Trends and Effects on the Construction Workforce. *Center for Construction Industry Studies*, (14).

Hawk, D. (1992). Forming a new industry-international building production. *Swedish Council for Building Research*.

Hindle, T. (2009a, March 16). Strategic planning. *The Economist*, pp. 1–2.

Hindle, T. (2009b, March 30). Vertical integration. *2The Economist*, pp. 8–11. Retrieved from www.economist.com/node/13396061

Hindle, T. (2009c, November 19). Value chain. *The Economist*, pp. 8–11. Retrieved from www.economist.com/node/14301710

HM Revenue & Customs (HMRC). (2013). CISR13020 - The Scheme : subcontractors : definition of subcontractor. *CISR 13020*.

Hubbard, B., Middaugh, B., Zimmerman, N., & McGlothlin, J. (2009). Utilizing an Analytic Hierarchy Process (AHP) to Assess Concrete Saws with Silica Dust Reduction Equipment. *CIB W099 Conference*.

Humphreys, P., McIvor, R., & Huang, G. (2002). An expert system for evaluating the make or buy decision. *Computers & Industrial Engineering*, *42*(2-4), 567–585. doi:10.1016/S0360-8352(02)00052-9

Ibrahim, A. R. Bin, Roy, M. H., Ahmed, Z. U., & Imtiaz, G. (2010). Analyzing the dynamics of the global construction industry: past, present and future. *Benchmarking: An International Journal*, *17*(2), 232–252. doi:10.1108/14635771011036320

Isik, Z., Arditi, D., Dilmen, I., & Birgonul, M. T. (2010). The role of exogenous factors in the strategic performance of construction companies. *Engineering, Construction and Architectural Management*, *17*(2), 119–134. doi:10.1108/09699981011024650

Jensen, P., Hamon, E., & Olofsson, T. (2009). Product Development Through Lean Design and Modularization Principles. *International Group of Lean Construction*, 465–474. Retrieved from http://pure.ltu.se/portal/files/3334127/Jensen_Hamon_Olofsson_2009_Product_development_through_lean_design_and_modularization_principles.pdf

Kärnä, S., & Junnonen, J.-M. (2005). Project feedback as a tool for learning. *International Group of Lean Construction*, *13*, 12. Retrieved from http://www.cem.tkk.fi/fsr/Propal/management/Project feedback as a tool for learning.pdf

Kennedy, T. (2009). Advancing the Competitiveness and Efficiency of the U.S. Construction Industry.

Koskela, L. (1998). Foundations of Concurrent Engineering. *Concurrent Engineering in Construction Projects*, 12–29.

Lacity, M. C., & Hirschheim, R. A. (1995). *The information systems outsourcing bandwagon* (p. 237). New York: Chichester.

Libaw, O. (1997). Rebuilding the construction industry. *Business Mexico*, *7*(5), 32–35. Retrieved from http://search.proquest.com.ezproxy.lib.purdue.edu/docview/197138010?accountid=13360

Lin, Y., Parlakturk, A. K., & Swaminathan, J. M. (2013). Vertical Integration under Competition: Forward, Backward, or No Integration? *Forthcoming in Production and Operations Management Vertical*, 30.

Louwe, J. B. M., & van Eck, M. (1992). Future Organization of the Building Process. *CIB1*.

Martin, P. (2012). Migration and Competitiveness in US Construction and Meatpacking.

Murray, M., & Langford, D. (2003). *Construction Reports 1944-98* (p. 239). Oxford: Blackwell Science Ltd. doi:10.1002/9780470758526

Nadim, W., & Goulding, J. S. (2010). Offsite production in the UK: the way forward? A UK construction industry perspective. *Construction Innovation: Information, Process, Management*, *10*(2), 181–202. doi:10.1108/14714171011037183

Nam, C. H., & Tatum, C. B. (1988). Major characteristics of constructed products and resulting limitations of construction technology Major characteristics of constructed products and resulting limitations of construction technology. *Construction Management and Economics*, *6*(2), 133–147. doi:10.1080/01446198800000012

Ng, S., & Skitmore, R. (2002). Contractors' risks in Design, Novate and Construct contracts. *International Journal of Project Management*, (20), 119 – 126. Retrieved from http://www.sciencedirect.com/science/article/pii/S026378630000051X

Peng, M. W., Zhou, Y., & York, A. S. (2006). Behind make or buy decisions in export strategy: A replication and extension of Trabold. *Journal of World Business*, *41*(3), 289–300. doi:10.1016/j.jwb.2006.01.006

Perera, S., Davis, S., & Marosszeky, M. (2010). Head Contractor Role in Construction Management from a Value Perspective. *International Group for Lean Construction*, 83–91.

Platts, K. W., Probert, D. R., & Cañez, L. (2002). Make vs . buy decisions : A process incorporating multi-attribute, *77*, 247–257.

Porter, M. E. (2008). The Five Competitive Forces that Shape Strategy. *Harvard Business Review*, *86*(1), 78–94.

Prasad Chennupati, S. B. (2013). Development of risk mitigation tool to mitigate risks in supply networks. *Purdue University*, 81. Retrieved from https://www.cerias.purdue.edu/assets/pdf/bibtex_archive/2009-38.pdf

Pries, F., & Janszen, F. (1995). Innovation in the construction industry: the dominant role of the environment. *Construction Management and Economics*, *13*, 43–51.

Rothaermel, F. T. (2013). *Strategic Management: Concepts and Cases* (p. 747). New York.

Saaty, T. L. (1982). *Decision making for leaders: the analytical hierarchy process for decisions in a complex world* (p. 291). California: Belmont, Calif. : Lifetime Learning Publications. Retrieved from https://purdue-primo-prod.hosted.exlibrisgroup.com/record/PURDUE_ALMA21528964930001081

Schleifer, T. C. (1990). *Construction Contractor's Survival Guide* (p. 155). Wiley-Interscience Publication.

Sears. (2013). Sears Historic Homes. Retrieved from http://www.searsarchives.com/homes/

Shahzad, W. M., & Mbachu, J. (2012). *Productivity Enhacement of Construction Industry using Prefabrication Impact Levels of the Underlaying Constrains and Improvement Measures* (p. 137). Aukland: LAP LAMBERT Academic Publishing.

Shapira, A., & Simcha, M. (2009). AHP-Based Weighting of Factors Affecting Safety on Construction Sites with Tower Cranes. *Journal of Construction Engineering and Management*, (April), 307–318.

SIC. (2013). Standard Industrial Classification. Retrieved from http://siccode.com/en/

Soto, S. (2010). *Desarrollo de una estrategia de prevención de No Conformidades Críticas para la ejecución de Proyectos de edificaciones*. UPC.

US Census Bureau. (2012). 2012 Economic Census Business Help Site. *Sector 23: Construction*. Retrieved from http://bhs.econ.census.gov/ec12/cc-23/sec_cc-23.html

Wells, J. (1985). The role of construction in economics growth and development. *Habitat International*, *9*(1), 55–70.

APPENDICES

Appendix A: Survey Instrument

Survey on Modularization and Prefabrication

Prefabrication

Survey on Prefabrication
Purpose of Research
This survey is aimed at collecting information on perspectives from construction professionals regarding the business parameters that should be analyzed for a company to decide between self-performing (making) or subcontracting (buying) prefabricated components for their projects. Survey Logistics Your participation in this survey is voluntary and anonymous, and the respondent can skip any question. This survey contains 19 questions divided by multiple choice, open questions to explain some of the multiple choice answers, agree or disagree questions (scale 1 to 5), 5 ranking questions and final comments. The survey should take approximately 15 minutes. If you have any questions or comments about this survey, feel free to contact Sebastian Soto at ssotoort@purdue.edu or at (765) 543-4275. As a large construction general contractor, your response and feedback are important to help identify the business parameters that should be analyzed for a company to decide between self-performing (making) or subcontracting (buying) prefabricated components for their projects. I sincerely appreciate your time and effort in responding to this survey. Definition Prefabrication Is the practice of assembling components of a structure in a manufacturing site, and transporting complete assemblies or sub-assemblies to the construction site where the structure is to be located. It differs from the conventional construction practice because the elements are fabricated beforehand in a different place and then transported to the construction site where all the assembly is carried out.

Q1 How many years of professional experience do you have?
- ❍ Less than 5 years (1)
- ❍ 5 to 10 years (2)
- ❍ 11 to 15 years (3)
- ❍ 16 to 20 years (4)
- ❍ More than 20 years (5)

Q2 What describes the pr ml;]1\212; imary function of the company you work for in the construction industry?
- ❍ General Contractor (1)
- ❍ Subcontractor (2)
- ❍ Supplier (3)
- ❍ PM Consultant (4)
- ❍ Design and Engineering (5)
- ❍ Other: (6) _____

Q3 What are the main type of projects your firm constructs?

- ❑ Residential (1)
- ❑ Commercial (2)
- ❑ Industrial (3)
- ❑ Heavy civil (roads & bridges) (4)
- ❑ Other: (5) _____

Q4 Do you believe that:

Table A.1: Survey Question 4

	Strongly Disagree (1)	Disagree (2)	Neither Agree nor Disagree (3)	Agree (4)	Strongly Agree (5)
Prefabrication is a current trend applicable to your current projects (1)	❍	❍	❍	❍	❍
Prefabrication can become a long term solution to improve construction performance (2)	❍	❍	❍	❍	❍

Q5 What type of off-site construction/fabrication of building systems has your company performed?

Table A.2: Survey Question 5

	Performed by GC (1)	Performed by Subcontractor (2)
HVAC (1)	❍	❍
Wall Panels (2)	❍	❍
Precast (3)	❍	❍
Electrical (4)	❍	❍
Bathrooms (5)	❍	❍
Other (a) (6)	❍	❍
Other (b) (7)	❍	❍

Q6 Has your company ever set-up a temporary facility to build prefabricated components?

❍ Yes (1)
❍ No (Skip to Question 9) (2)

Q7 Was there a difference in how you handled the safety procedures of your temporary facility versus the construction site?

❍ Yes (1)
❍ No (2)
❍ Don't know (3)

Q8 Did you consult or have experience with manufacturing safety principles?

❍ Yes (1)
❍ No (2)
❍ Don't Know (3)

Q9 Have you ever directly participated in the off-site prefabrication of construction components during your professional career?

❍ Yes (1)
❍ No (2)

Q10 When working or studying the use of prefabrication for your projects, did you consider opening a temporary facility to prefabricate the elements yourself or outsourcing the work?

❍ Temporary facility (1)
❍ Outsource the work (2)
❍ Both (3)
❍ None (Skip to Question 12) (4)

Q11 What were the reasons for your choice?

Q12 Do you believe that setting up a division solely for prefabrication within your firm could be a new business opportunity for Construction Companies?
❍ Yes (1)
❍ No (2)

Q13 Please Explain:

Q14 Has your company recently developed a business plan that involves changing from subcontracting to self-performing more construction activities?
❍ Yes (1)
❍ No (2)
❍ Don't know (3)

Q15 Please Explain:

Q16 According to your experience, please rank what you consider the most important restrictions to use prefabrication in your industry. Sort from 1 to 10, 1 being the first restriction that you consider the most important to use it and 10 the lease important.Note: to rank, click on the option and drag it with the mouse.
_____ Very little or none integration between planning, design, manufacturing, supply and installation in the projects (1)
_____ Prefabricated projects are more expensive than traditional site-built projects (2)
_____ Lack or insufficient building codes to facilitate prefabrication (3)
_____ Considerable labor limitations on the job site (lack of skills, safety and/or quality knowledge) (4)
_____ Considerable labor limitations on prefabs plants (lack of skills, safety and/or quality knowledge) (5)
_____ Clients preference for on-site building (6)
_____ Limited capacity of other subcontractors to coordinate and perform with the prefabrication activities (7)
_____ Job site restrictions (8)
_____ Type of project (9)
_____ Other: (10)

Q17 Provide a list of the top reasons in order to subcontract or buy prefabricated components from a different firm:
a) _____ (1)
b) _____ (2)
c) _____ (3)
d) _____ (4)
e) _____ (5)

Q18 Provide a list of the top reasons in order to self-perform prefabricated components:
a) _____ (1)
b) _____ (2)
c) _____ (3)
d) _____ (4)
e) _____ (5)

Q19 Final Comments:

Appendix B: Email template

Dear Respondent:

My name is Sebastian Soto and I'm a graduate student at Purdue University in the BCM program. I talked to professor _____ and he suggested me to contact you to ask for your help.

I'm currently working on my thesis and my objective is to identify general parameters for a construction company to decide between subcontracting or self-performing prefabrication activities for their projects.

For this reason, I have developed a survey to help us identify some of these general parameters based on the experience of construction professionals such as yourself. Please, share some of your experience in the topic by filling the online survey at https://purdue.qualtrics.com/SE/?SID=SV_2m1MkjfqL8MszMp. And please, if you know someone else who might provide useful information and should be included in this survey please feel free to forward the link.

The survey contains 19 questions total, but if you don't know about a certain topic or prefer not to answer you are free to skip any question. If you have any questions please email me at ssotoort@purdue.edu or you can call me or contact me through whatsapp, facetime or viber at +1 (765) 543-4275.

Again, thank you very much for your time and for sharing a little of your experience and I hope you have a great time during these holidays.

--
Regards,

Sebastian Soto
Graduate Student
College of Technology - Building Construction Management

--

Survey on Prefabrication

Purpose of the Research

This survey is aimed at collecting information on perspectives from construction professionals regarding the business parameters that should be analyzed for a company to decide between self-performing (making) or subcontracting (buying) prefabricated components for their projects

Survey Logistics

Your participation in this survey is voluntary and anonymous, and the respondent can skip any question. This survey contains 19 questions divided by multiple choice, open questions to explain some of the multiple choice answers, agree or disagree questions (scale 1 to 5), 5 ranking questions and final comments. The survey should take approximately 15 minutes. If you have any questions or comments about this survey, feel free to contact Sebastian Soto atssotoort@purdue.edu or at (765) 543-4275.

As a large construction general contractor, your response and feedback are important to help identify the business parameters that should be analyzed for a company to decide between self-performing (making) or subcontracting (buying) prefabricated components for their projects. I sincerely appreciate your time and effort in responding to this survey.

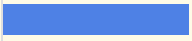
Definition
Prefabrication
Is the practice of assembling components of a structure in a manufacturing site, and transporting complete assemblies or sub-assemblies to the construction site where the structure is to be located. It differs from the conventional construction practice because the elements are fabricated beforehand in a different place and then transported to the construction site where all the assembly is carried out.

Appendix C: Qualtrics Report

My Report
Last Modified: 01/15/2014

Table A.3: Qualtrics report for Question 1

1. How many years of professional experience do you have?

#	Answer		Response	%
1	Less than 5 years		3	13%
2	5 to 10 years		0	0%
3	11 to 15 years		4	17%
4	16 to 20 years		7	30%
5	More than 20 years		9	39%
	Total		23	100%

Statistic	Value
Min Value	1
Max Value	5
Mean	3.83
Variance	1.79
Standard Deviation	1.34
Total Responses	23

Table A.4: Qualtrics report for Question 2

2. What describes the primary function of the company you work for in the construction industry?

#	Answer		Response	%
1	General Contractor		11	50%
2	Subcontractor		4	18%
3	Supplier		0	0%
4	PM Consultant		1	5%
5	Design and Engineering		1	5%
6	Other:		5	23%
	Total		22	100%

Other:
Electrical
Owner [a.k.a. Refiner, Operator]
All the above
Education and Consulting

Statistic	Value
Min Value	1
Max Value	6
Mean	2.64
Variance	4.53
Standard Deviation	2.13
Total Responses	22

Table A.5: Qualtrics report for Question 3

3. What are the main type of projects your firm constructs?

#	Answer		Response	%
1	Residential		2	9%
2	Commercial		10	43%
3	Industrial		16	70%
4	Heavy civil (roads & bridges)		2	9%
5	Other:		3	13%

Other:
50% Commercial and 50% Industrial
Everything: Oil & gas, infrastructure, commercial bldgs, utility systems (because we are a national oil company)
Tunneling, mining infrastructure, dams, hydroelectrics

Statistic	Value
Min Value	1
Max Value	5
Total Responses	23

Table A.6: Qualtrics report for Question 4

4. Do you believe that:

#	Question	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree	Total Responses	Mean
1	Prefabrication is a current trend applicable to your current projects	1	1	1	10	10	23	4.17
2	Prefabrication can become a long term solution to improve construction performance	1	1	2	6	13	23	4.26

Statistic	Prefabrication is a current trend applicable to your current projects	Prefabrication can become a long term solution to improve construction performance
Min Value	1	1
Max Value	5	5
Mean	4.17	4.26
Variance	1.06	1.20
Standard Deviation	1.03	1.10
Total Responses	23	23

Table A.7: Qualtrics report for Question 5

5. What type of off-site construction/fabrication of building systems has your company performed?

#	Question	Performed by GC	Performed by Subcontractor	Total Responses	Mean
1	HVAC	3	11	14	1.79
2	Wall Panels	8	5	13	1.38
3	Precast	5	8	13	1.62
4	Electrical	1	12	13	1.92
5	Bathrooms	1	5	6	1.83
6	Other (a)	2	7	9	1.78
7	Other (b)	2	2	4	1.50

Other (a)	Other (b)
Structural steel	
Oil & gas modules	Chiller, mech pkgs
M&E Modules	
Plumbing	
Elec/Mech Utility Racks	
Too Numerous to mention	
Pipe Racks	Structral Steel

Statistic	HVAC	Wall Panels	Precast	Electrical	Bathrooms	Other (a)	Other (b)
Min Value	1	1	1	1	1	1	1
Max Value	2	2	2	2	2	2	2
Mean	1.79	1.38	1.62	1.92	1.83	1.78	1.50
Variance	0.18	0.26	0.26	0.08	0.17	0.19	0.33
Standard Deviation	0.43	0.51	0.51	0.28	0.41	0.44	0.58
Total Responses	14	13	13	13	6	9	4

Table A.8: Qualtrics report for Question 6

6. Has your company ever set-up a temporary facility to build prefabricated components?

#	Answer		Response	%
1	Yes		11	48%
2	No (Skip to Question 9)		12	52%
	Total		23	100%

Statistic	Value
Min Value	1
Max Value	2
Mean	1.52
Variance	0.26
Standard Deviation	0.51
Total Responses	23

Table A.9: Qualtrics report for Question 7

7. Was there a difference in how you handled the safety procedures of your temporary facility versus the construction site?

#	Answer		Response	%
1	Yes		3	27%
2	No		8	73%
3	Don't know		0	0%
	Total		11	100%

Statistic	Value
Min Value	1
Max Value	2
Mean	1.73
Variance	0.22
Standard Deviation	0.47
Total Responses	11

Table A.10: Qualtrics report for Question 8

8. Did you consult or have experience with manufacturing safety principles?

#	Answer		Response	%
1	Yes		5	45%
2	No		6	55%
3	Don't Know		0	0%
	Total		11	100%

Statistic	Value
Min Value	1
Max Value	2
Mean	1.55
Variance	0.27
Standard Deviation	0.52
Total Responses	11

Table A.11: Qualtrics report for Question 9

9. Have you ever directly participated in the off-site prefabrication of construction components during your professional career?

#	Answer		Response	%
1	Yes		17	74%
2	No		6	26%
	Total		23	100%

Statistic	Value
Min Value	1
Max Value	2
Mean	1.26
Variance	0.20
Standard Deviation	0.45
Total Responses	23

Table A.12: Qualtrics report for Question 10

10. When working or studying the use of prefabrication for your projects, did you consider opening a temporary facility to prefabricate the elements yourself or outsourcing the work?

#	Answer		Response	%
1	Temporary facility		5	22%
2	Outsource the work		6	26%
3	Both		11	48%
4	None (Skip to Question 12)		1	4%
	Total		23	100%

Statistic	Value
Min Value	1
Max Value	4
Mean	2.35
Variance	0.78
Standard Deviation	0.88
Total Responses	23

Table A.13: Qualtrics report for Question 11

11. What were the reasons for your choice?

Text Response
Cost of temporary facilities for prefabricating items for one project make prefabricating cost-prohibitive.

Statistic	Value
Total Responses	1

Table A.14: Qualtrics report for Question 12

12. Do you believe that setting up a division solely for prefabrication within your firm could be a new business opportunity for Construction Companies?

#	Answer		Response	%
1	Yes		11	55%
2	No		9	45%
	Total		20	100%

Statistic	Value
Min Value	1
Max Value	2
Mean	1.45
Variance	0.26
Standard Deviation	0.51
Total Responses	20

Table A.15: Qualtrics report for Question 13

13. Please Explain:

Text Response
In Peru there are very few companies that currently do or use this type of work, so this can be a competitive advantage for the company in future bids. Also, projects are getting more complex because the budgets and time limits are becoming tightier every time.
I think you need to focus on your business plan. Non Focus means loss profits. If you are going to do prefab, then do it for your own company. If you are going to do prefab for the industry, then get out of the construction business.
Recent econony has companies looking to lower overhead costs especially in the publicly held sector. Outsourcing is a tremendous help in not only lowering production costs but also lowering overhead costs since that outsourced work cost is job cost and not an overhead cost.
Better productivity rates may be achieved. There is an improvement on quality and a reduction of waste. The jobsite becomes safer. Less construction time on site and commissioning allows to save also on job overhead.
The national oil company I work for has a goal of increasing the number of Saudis who work within the Company. This goal negates the cost-time savings objectives that drives modular projects.
it depends on the business objectives of the organization
If logistics of prefabricating repetative assemblies for projects and the delivery of those assemblies can be incoporated into multiple projects, and the challenge of dealing with jurisdictional inspections of the work offsite can be overcome, quality and speed of construction benefits.
Typically - prefabrication and outsourcing to other competitors is not a practice within the industry.

Table A.15 continued

In local market there are not many companies offering prefabrication, and they get pretty good profits of this business. In other words, there is a space, we can get the knowhow of previous isolated experiences, and we have an in house market to start developing this business.
In the past two years we have had successful pre-fab Elec/Mech utility rack projects. These projects were specific to an overall larger project and/or Client. We have had discussions about initiating a Pre-Fab business model and going to market to other Clients and larger EPC (Engineer-Procure-Construction) firms for these services as stand alone. Very preliminary discussion thus far.
We have it setup that way currently and 50% of our prefab division does work for other companies
The prefabrication has to be set up around a business model that is nearly self supporting. It has to have outside customers as well.
It is not a viable option for us as in many cases sub contractors can perform that work at reduced cost. If a super project of some sort where the cost is effective and we need control over quality and design, probably.
There are too many variables that give uncertainty on the demand for prefabricated products.

Statistic	Value
Total Responses	14

Table A.16: Qualtrics report for Question 14

14. Has your company recently developed a business plan that involves changing from subcontracting to self-performing more construction activities?

#	Answer		Response	%
1	Yes		7	39%
2	No		11	61%
	Total		18	100%

Statistic	Value
Min Value	1
Max Value	2
Mean	1.61
Variance	0.25
Standard Deviation	0.50
Total Responses	18

Table A.17: Qualtrics report for Question 15

15. Please Explain:	
Text Response	
Usually all the construction was subcontracted, however starting about a year ago the company began constructing its projects by itself.	
We are a electrical Subcontractor	
We have done the opposite by outsourcing in lieu of self performing.	
The times the firm had to prefabricate we did self-performed it. The exception is for Project where we used prefabricated slabs, which are typically outsourced. We are currently evaluating self-performing that activity as well.	
We S/C everything to E/P/Cs. This question is not really written in a way that people who work for Owners can answer.	
We have added elements we self perform to our portfolio over the last several years.	
We have got a requirement from one important client on the biggest housing Project we ever have being involved, to fabricate 29 Km of precast perimeter walls. They gave us only 2 months time frame to complete this task, including installation. Local supplier only 2 commit to participate taking part of the production goal. We evaluate the option, times, and costs, and decided to take 10 Km ourselves. This effort will give a 16% gross profit once it will be completed.	
We self-perform a lot of work ourselves already. Anywhere from 40% to 70% is self-performed at this time.	
We already have a prefabrication division.	
There are some activities that GC's usually have labor for and that labor can perform other activities that tend to be subcontracted.	
Statistic	Value
Total Responses	10

Table A.18: Qualtrics report for Question 16

16. According to your experience, please rank what you consider the most important restrictions to use prefabrication in your industry. Sort from 1 to 10, 1 being the first restriction that you consider the most important to use it and 10 the lease important.Note: to rank, click on the option and drag it with the mouse.

#	Answer	1	2	3	4	5	6	7	8	9	10	Total Responses
1	Very little or none integration between planning, design, manufacturing, supply and installation in the projects	3	4	4	3	1	2	0	2	0	0	19
2	Prefabricated projects are more expensive than traditional site-built projects	1	1	1	2	3	0	2	5	3	1	19
3	Lack or insufficient building codes to facilitate prefabrication	1	1	3	2	4	0	1	2	5	0	19
4	Considerable labor limitations on the job site (lack of skills, safety and/or quality knowledge)	2	1	2	2	3	2	5	0	1	1	19
5	Considerable labor limitations on prefabs plants (lack of skills, safety and/or quality knowledge)	1	0	1	2	1	5	5	2	1	1	19

Table A.18 continued

6	Clients preference for on-site building	2	1	3	2	3	0	2	2	4	0	19
7	Limited capacity of other subcontractors to coordinate and perform with the prefabrication activities	0	2	1	6	1	4	2	2	0	1	19
8	Job site restrictions	2	3	4	0	0	5	2	1	2	0	19
9	Type of project	6	4	0	0	2	1	0	3	3	0	19
10	Other:	1	2	0	0	1	0	0	0	0	15	19
	Total	19	19	19	19	19	19	19	19	19	19	-

Other:
Owner Changes after prefab is done is more costly and the owners do not want to pay for the product that has been produced. Window for changes is shorter
Union considerations
Unavailability of equipment such as tower cranes with high load capacity, land extensions big enough to set up a plant are too expensive.
Ignorance of what can be pre-fabricated
Labor union receptivity

Table A.19: Qualtrics statistic report for Question 16

Statistic	Very little or none integration between planning, design, manufacturing, supply and installation in the projects	Prefabricated projects are more expensive than traditional site-built projects	Lack or insufficient building codes to facilitate prefabrication	Considerable labor limitations on the job site (lack of skills, safety and/or quality knowledge)	Considerable labor limitations on prefabs plants (lack of skills, safety and/or quality knowledge)	Clients preference for on-site building	Limited capacity of other subcontractors to coordinate and perform with the prefabrication activities	Job site restrictions	Type of project	Other:
Min Value	1	1	1	1	1	1	2	1	1	1
Max Value	8	10	9	10	10	9	10	9	9	10
Mean	3.58	6.32	5.68	5.21	6.16	5.37	5.26	4.74	4.26	8.42
Variance	4.70	6.89	7.34	6.29	4.47	7.91	4.54	7.09	10.98	10.4
Standard Deviation	2.17	2.63	2.71	2.51	2.12	2.81	2.13	2.66	3.31	3.22
Total Responses	19	19	19	19	19	19	19	19	19	19

Table A.20: Qualtrics report for Question 17

17. Provide a list of the top reasons in order to subcontract or buy prefabricated components from a different firm:

a)	b)	c)	d)	e)
If the company will just use prefabrication in few projects	No need to have qualified staff	Probably will be cheaper as the other company has the know-how		
If they are less expensive	Faster delivery	stock item		
Lower overall cost of installed product	Reduced overhead costs			

Table A.20 continued

Reduced production capacity and short response time of a determined requirement.	Lack of knowledge of the prefabrication process that may be too complex.			
Whether or not the technology is a "black box" .. patented, etc.	Amount of competition	Schedule	Site location & weather	Cost savings
Know-how on the integrated product				
They are ususally specialized in the fabrication of those components	Not enough constant volume to bring in house	Transfers warranty to subcontractor / suppliers		
Risk of errors or problems is passed down from the GC to a lower-tier firm	Expertise	Existing resources / facilities		
Balance risk on certain types of projects				
Cost	Deliverables	Safety	Schedule or turnover	
Fix our target price and profit	Reduce construction schedule	Focus on main business	Lack of space at jobsite	Speciality from subcontracting firm

Table A.20 continued

Specialized system that the sub deals with day to day and we may not be familiar	On site Client restrictions negatively impact productivity....off site more efficient.	Perhaps an off site controlled (temp, humidity, etc..) environment is needed to do certain work activities (welding)	For remote jobsites, getting materials to site can be cost prohibitive whereas a more centralized pre-fab location makes more sense	
do a cost analysis	If the prefab shop in house is to busy			
Steadyness of work	Skill set needed	Location of worksite		
Reducing resposability of the GC	Subcontractors tend to have highly specialized and trained labor	Better trained labor translates into safety	No startup costs involved	

Statistic	Value
Total Responses	15

Table A.21: Qualtrics report for Question 18

18. Provide a list of the top reasons in order to self-perform prefabricated components:				
a)	b)	c)	d)	e)
If prefabrication will be used continuously	I would use this as a technical advantage when bidding for future projects	If I subcontract another company to do the prefabs, that company is going to have an advantage over me and that could mean they will get more projects than me in the future		
Control	Custom	Training of work force		
Logistics of delivery and placement of final product	Union jurisdictional issues	Lack of time to preplan and have delivered to site		
Better productivity rates, better quality and safer conditions.	Highly specialized labor requires less quality controls.	Higher industrialization of the construction process.		
Delusional thinking (why would someone jump into a deep pool not knowing how to swim?)	Necessity	Competitive needs (1st to market, desire to commercialize/prove a concept)	Business downturn causing a company to keep resources utilized	Dis-satisfaction with local E/P/Cs
Higher level of control				
Enhance profitability	Better schedule control			
Control of costs	Control of quality	Control of schedule / resources	Retain profits	
Contol				
Limit risk	Cost	Schedule or turnover		

Table A.21 continued

Increase project´s profit	reduce construction schedule	reduce variability	operational excellence	innovation
Control the schedule better	Better able to plan and coordinate the pre-fab component into the overall system	Keep our Key personnel working if the Company is low on workload	We are predominately a Union shop and sometimes that can conflict with certain pre-fab systems (particularly Mechanical) and doing it ourselves more economical than a Subcontracted Union shop	
Control	better communication			
Matches skillset of needed components	Have the ability to accurately plan work	Can perform work at lower overall cost		
More control in the production flow	Better control on quality	Less risk because of more control	The know how stays in the company	

Statistic	Value
Total Responses	15

Table A.22: Qualtrics report for Question 19

19. Final Comments:	
Text Response	
I would like you to explain question 16. I have no idea what you are asking. Is it 1-10, 1 being the best reason to use prefab on a project? Or is 1-10, 1 being the reason why you would not use fab?	
I worked for UOP-Honeywell's Modular Equipment group from '93-'04. It is a very competitive industry. Outside of non-competitive national oil companies, modular works are considered more often. The disdain for modular jobs is in the spacial realities that the owner ends up with. I did not care for the question where I was asked to force rank 10 items. Sorry.	
I do think the future for construction is in prefabrication where possible. Challanges exist in renovation projects or in areas where union jursistictions conflict.	
Prefabrication is a huge, mostly untapped opportunity to advance the use of technology and quality in our industry.	
Each Project should be evaluated from early stages (design) about the possibility of using precast. If a contractor gets an already designed Project, a value engineering process should also be carried out in order to decide on prefabrication. The decisión wether to subcontract or self perform should always be evaluted as an option, based on the resources, knowhow, and experience on previous projects.	
Pre-fabrication philosophy is not new but it seem to have taken on renewed interest. I believe research in this area at this time is quite applicable to the Construction Industry.	
Statistic	Value
Total Responses	6

Appendix D: Decision making tool example – Information sheet

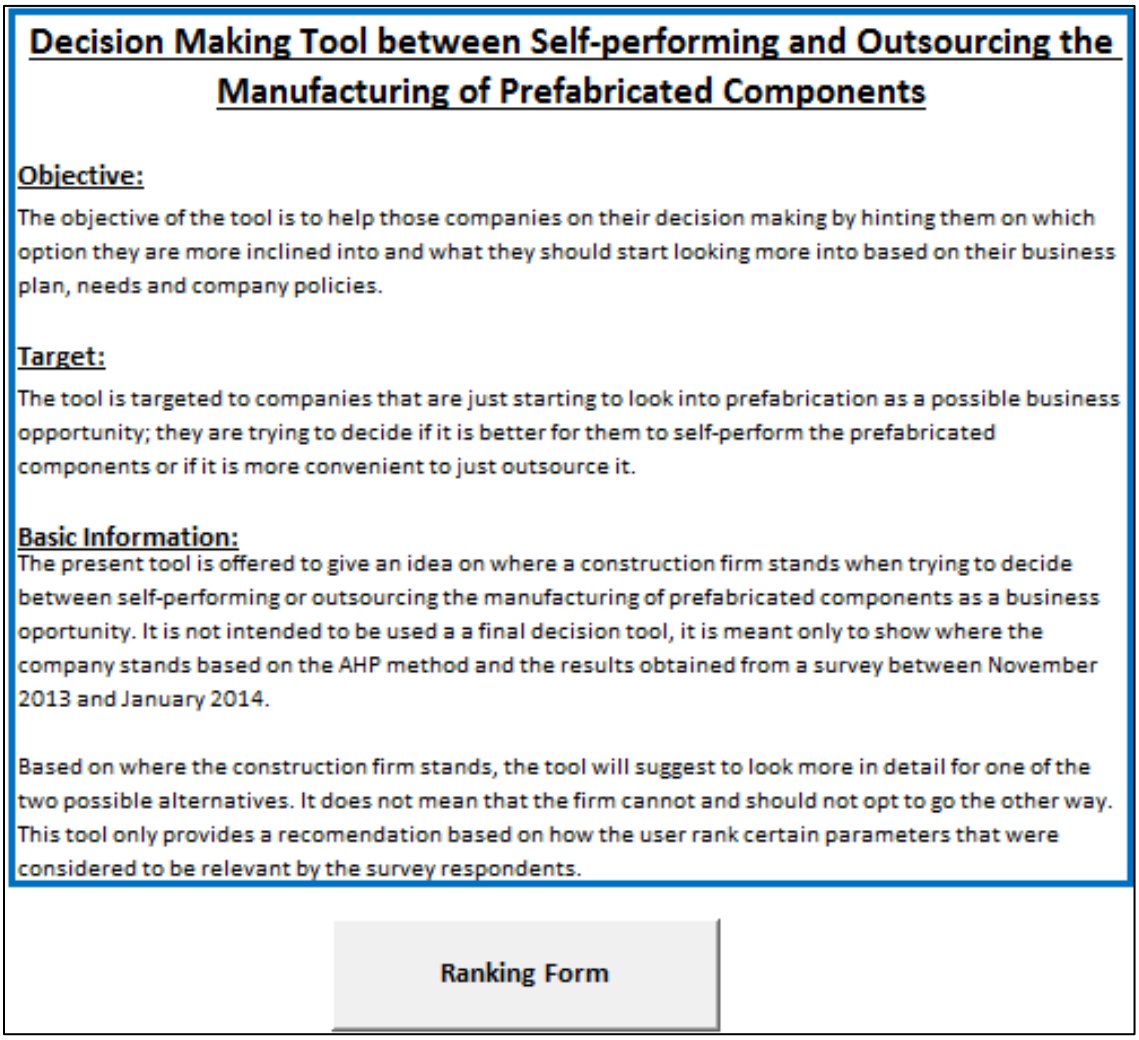


Figure A.1: Screenshot of the Information Sheet.

Appendix E: Decision making tool example – Ranking sheet

Table A.23: Example of the Ranking Sheet

Ranking Form

Instructions:

Please rank in order of importance according to your company's needs and requirements for prefabricating elements, being 1 the most important and 8 the least important.

	Rank
Onsite resources Optimization This refers to contractors wanting to optimize the use of company labor and improve planning.	3
Risk reduction This refers to the reduction of the contractor's risk. Some examples are: • Sharing/transferring risks with other parties. • Reducing overhead. • Reducing skilled labor on site.	6
Enhance profitability This refers to the reduction of the contractor's objective to: • Reduce costs. • Increase their profits.	8
Front End Schedule Control This refers to the reduction and control the projects schedule by: • Not needing time to set up a facility prior to the start of a project. • Design does not need to be complete prior to construction.	1
Stabilize Workload Across Company This refers to the company workload depending on: • Unknown forthcoming projects. • Long term staffing needs.	4
Control of Quality, Safety, and Schedule This refers to contractors having: • Better Control of Quality, Safety, and Schedule. • More control of project logistics. • Fewer subcontractors.	2

Table A.23 continued

Strong Relationships with Subcontractors that can prefabricate components Construction firms have relationships with: • Highly skilled prefabrication subcontractors. • Subcontractors with sufficient facilities, labor and equipment.	5
Protection of intellectual property and core competencies This refers to the reduction of the contractor's wanting to keep specific know-how in the company.	7

Appendix F: Decision making tool example – Calculation sheet

Table A.24: Example of the Calculation Sheet (Outsourcing)

Outsourcing									
Reasons		**Points**	**Group Points**	**Group %**	**Ranked**	**Score**	**Group scores after factors**	**Total score**	**Percentage**
Risk reduction	Reduce construction cost by reducing job overhead and labor	7	11	28.95%	6.00	3.00	0.87	4.34	46%
	Share the risks with other parties	4							
Front End Schedule Control	Have Fast Delivery of prefabricated components / Schedule effective	5	5	13.16%	1.00	8.00	1.05		
Stabilize Workload Across Company	Number of projects / workload / personnel rotation	4	4	10.53%	4.00	5.00	0.53		
Strong Relationships with Subcontractors that can prefabricate components	Established site location	4	18	47.37%	5.00	4.00	1.89		
	Subcontractors are specialized and have better control of the Know-how	11							
	Subcontractors already have the resources / facilities	3							

Table A.25: Example of the Calculation Sheet (Self-Performing)

Self-Performing									
Reasons		**Points**	**Group Points**	**Group %**	**Ranked**	**Score**	**Group scores after factors**	**Total score**	**Percentage**
Control of Quality, Safety, and Schedule	Have better control over quality, safety, logistics and schedule	12	15	42.86%	2.00	7.00	3.00	5.11	54%
	Reduce risks by involving less parties	3							
Enhance profitability	Reduce costs and enhances profitability	6	6	17.14%	8.00	1.00	0.17		
Protection of intellectual property and core competencies	Keep the know-how in the company	4	4	11.43%	7.00	2.00	0.23		
Onsite resources Optimization	Stabilize the workload and own labor of the projects	7	10	28.57%	3.00	6.00	1.71		
	Reduce variability and improve planning	3							

Appendix G: Decision making tool example – Results sheet

Decision making tool to choose between self-performing and outsourcing the manufacturing of prefabricated components

Introduction:

Are you going to use prefabrication in one or more projects? Are you trying to decide if self-perform and outsource these activities? These may be some of the main questions asked by management when trying to decide on the following strategic moves for the company. Outsourcing is what is typically done in most activities in the construction industry, but some contractors may start studying if self-performing might make more sense according to their needs and objectives.

Self-Perform or outsource is a complex decision in the construction industry, there are many pros and cons for and against each other and there are also strong traditions and trends that limit innovation or change to what is typically done.

The following document analyzes the case of a construction firm that may be trying to change what is typically done and is placed in a situation in which they will have to use prefabrication and they will have to decide (for many and different reasons) the best option for them between self-performing or outsourcing the prefabricated components.

Definitions:

Outsourcing:

It is a strategy in which a company hires another to performed some of their work activities. In the construction industry, outsource is performed by subcontracting highly specialized companies.

In prefabrication outsourcing refers to subcontracting another company to run services "manufacturing" prefabricated components offsite at their own peril and with their own workers.

Prefabrication:

It is an industrial process in which certain components are manufactured in a specialized facility. These items will then be assembled or installed on the construction site. One might generalize by saying that any component manufactured off-site and requires to be assembled or installed to form a complete system can be considered as prefabricated.

Self-Performing:

Self-performing refers to a company executing some activities of a project on their own by using their own qualified labor, specialized equipment, and know-how to a project. In construction, self-performing is typically executed in critical activities. These allow the contractors to identify and solve construction challenges, offer scheduling flexibility and demand a level of quality and safety a typical contractor can’t.

Relating Self-performing to prefabrication means that a contractor would be in charge of setting up the offsite manufacturing facility and providing to themselves of the prefabricated components that will be assembled or installed in the project.

Reasons to:

Outsource prefabricated components:
Reduce construction cost by reducing job overhead and labor
Share the risks with other parties
Fast Delivery / Schedule effective
Number of projects / workload / personnel rotation
Established site location
Subcontracts are specialized and have better control of the Know-how
Reduce construction cost by reducing job overhead and labor

Self-Perform prefabricated components:
Better control over quality, safety, logistics and schedule
Reduces risks by involving less parties
Reduces costs and enhances profitability
Know-how stays in the company
Prefabrication helps stabilize the workload and labor
Reduce variability and improves planning

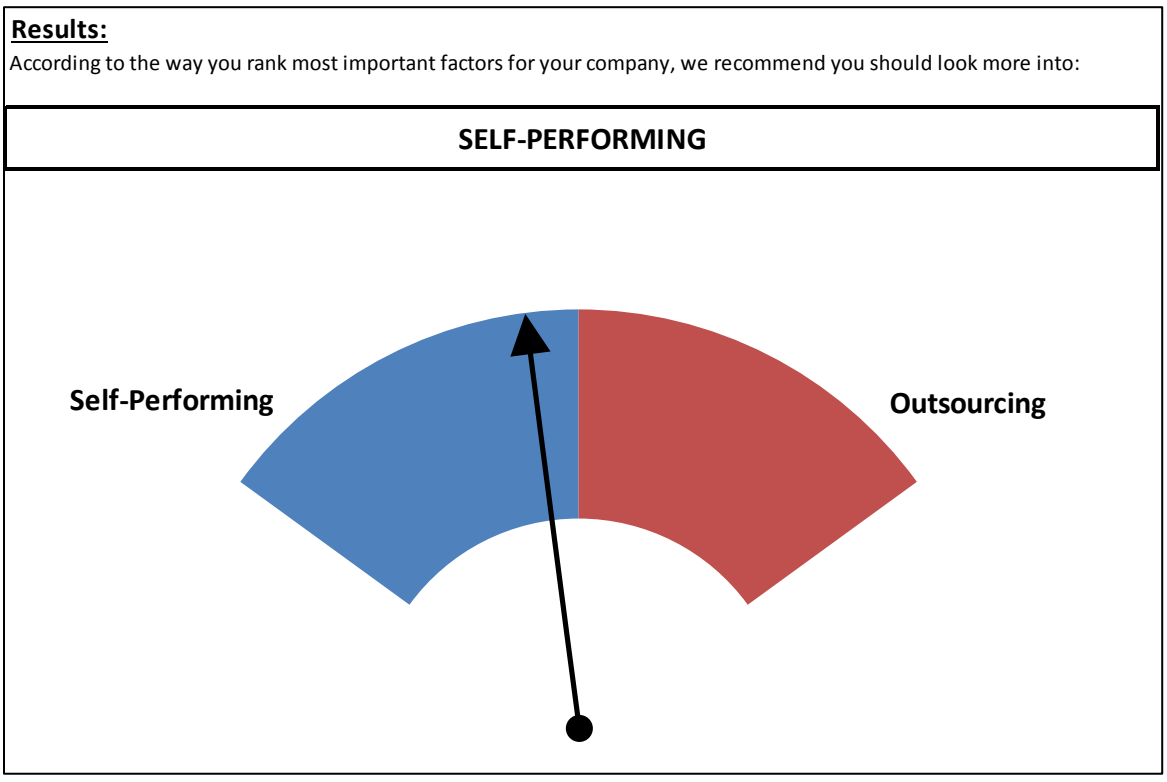


Figure A.2: Screenshot of the Results Gauge.